SKID RESISTANCE PERFORMANCE ENHANCEMENT USING DIFFERENT MACROTEXTURE PARAMETERS IN CHIP SEAL

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ABSTRACT

Transportation plays an important role to a country economic growth. As transportation is convenient to other economic activities such as construction industry and tourism, grows in other sectors will significantly affecting transportation industry as well. As a result of this situation, steady increases in the number of road crashes in every year from year 1997 to 2015 have been recorded. Skidding has been determined as one of the main causes of crash hence making an effort to determine the macrotexture characteristics of road pavements which include mean texture depth (MTD) and British Pendulum Number (BPN) is crucial. 21 numbers of asphalt concrete pavement samples were prepared for the purpose of laboratory works. Volumetric patch method and British pendulum test were used to examine MTD and BPN. The MTD results recorded from this research varied from 1.53 mm to 2.39 mm while the BPN obtained were varied from 57.7 to 114.5. MTD of 2.20 mm has been identified as the optimum skid resistance performance in this research. The value of correlation coefficient, R between MTD and BPN was 0.4748 showing that there was both parameters were positively correlated.

ABSTRAK

Pengangkutan memainkan peranan yang penting kepada pertumbuhan ekonomi negara. Aktiviti ekonomi yang lain seperti industri pembinaan dan pelancongan, tumbuh dalam sektor lain industri pengangkutan ketara akan mempengaruhi juga. Sebagai hasil dari keadaan ini, kenaikan mantap dalam bilangan kemalangan jalan raya pada setiap tahun dari tahun 1997 – 2015 telah direkodkan. Tergelincir telah ditetapkan sebagai salah satu punca utama kemalangan itu menjadikan usaha untuk menentukan ciri-ciri macrotexture turapan jalan termasuk kedalaman purata tekstur (MTD) dan British Pendulum Nombor (BPN) adalah amat penting. 21 nombor asfalt sampel turapan konkrit telah disediakan untuk tujuan kerja-kerja makmal. Cara patch isipadu dan ujian bandul British telah digunakan untuk memeriksa MTD dan BPN. Keputusan MTD direkodkan daripada kajian ini berbeza dari 1.53 mm hingga 2.39 mm manakala BPN diperolehi berbeza 57.7 dari 114.5. MTD 2.20 mm telah dikenal pasti sebagai prestasi rintangan gelinciran yang optimum dalam kajian ini. Nilai pekali korelasi, R antara MTD dan BPN adalah 0.4748 menunjukkan bahawa terdapat kedua-dua parameter telah dikaitkan secara positif.

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LIST OF SYMBOLS

R	Correlation coefficient
%	Percent
g	Gram
ml	Milliliter
℃	Degree Celsius

LIST OF ABBREVIATIONS

PIARC	World Road Association
MTD	Mean Texture Depth
MIROS	Malaysian Institute of Road Safety Research
BPN	British Pendulum Number
JKR	Public Works of Malaysia
TNZ	Transit New Zealand
ASTM	American Society for Testing and Materials
AC	Asphaltic Concrete
PCC	Portland Cement Concrete

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

1.1.1 Skid Resistance

Skid resistance can be understand as the frictional between tire and roads pavements. If road pavements has no skid resistance effect, the vehicles on road tend to be skidded which can cause crash.

There were many factors to influence skidding such as pavement surface type, aggregate type, pavement surface conditions, vehicles speed and driver ability. And these factors can be categorized into three categories which were tired-related factors (the composition of rubber tire, the life span of tire and the pressure of tire); pavement-related factors (pavement surface characteristics, microtexture and macrotexture); and intervening-substance-related factors (substances retain on road pavements surface and oil contaminants) (Shafii 2009).

1.1.2 Pavement Surface Characteristics

There were 4 levels of pavement texture as defined by World Road Association (PIARC) and Henry (2000) which are roughness, megatexture, macrotexture and microtexture. The wavelength of roughness was the biggest among others type of pavement surface whereas mircotexture was the smallest wavelength. The wavelength definition for each types of pavement surface characteristics were summarized as shown in Table 1.1.

Table 1.1: PIARC Texture Definitions

Texture level	Wavelengths
Microtexture	$\lambda < 0.5$ mm
Macrotexture	0.5 mm $< \lambda <$ 50 mm
Megatexture	50 mm $< \lambda <$ 0.5 m
Roughness	0.5 m $< \lambda <$ 50 m

Adapted from: Kuttesch *et al.* (2004)

Among these texture levels, 2 elements that received great interest in skid resistance were macrotexture and microtexture. Macrotexture characteristics can be interpreted as road having rough surface, while no macrotexture characteristics was referred to pavement with a smooth surface. Pavement having harsh surface can be interpreted as pavement having microtexture characteristics. Whereas pavement having polished surface can be understood as having no microtexture characteristics. With these 2 elements, pavement surface condition can be divided into four division: smooth and polished surface, smooth and harsh surface, rough and polished surface, rough and harsh surface (Kokkalis & Panagouli 1998).

In addition, microtexture played more important role when compared to macrotexture has been studied (Kokkalis & Panagouli 1998). However, macrotexture will influence more than microtexture in the pavement with wet condition and vehicles with high speed (Kokkalis & Panagouli 1998).

1.1.3 Macrotexture

Most of the research in macrotexture was discussing about the texture depth of pavement and its effectiveness to drain water out from pavement. The macrotexture having wavelength characteristics of 0.5 mm – 50 mm and amplitude characteristics with value of 0.1 mm – 20 mm (Ahammed & Tighe 2012). The difference between microtexture and macrotexture as shown in Figure 1.1.

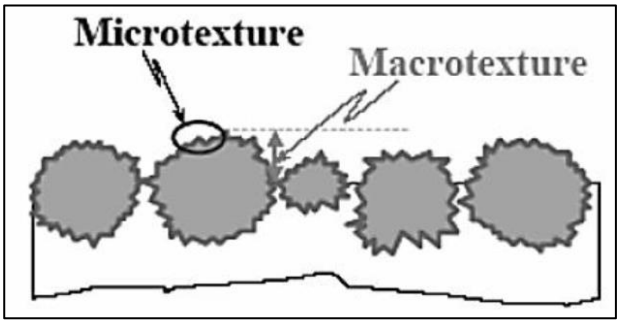

Figure 1.1: Difference between microtexture and macrotexture

Source: Baskara *et al.* (2016)

Georgiou & Loizos (2014) studied that macrotexture played a skid resistance performance role when vehicles speed was high. This finding has spark the interest towards this research where mean texture depth (MTD) has been selected as the macrotexture parameter to be investigated.

1.1.4 Chip Seal

Chip seal is located at the top surface of pavement. Chip seal is a combination of a layer of bituminous binder and a layer of aggregate. The effectiveness of the aggregate binder bond contributed mostly to the performance of chip seal (Aktaş, Karaşahin, Saltan, *et al.* 2013). Moreover, the surface of aggregate free of impurities showed a good skid resistance performance (Aktaş, Karaşahin, Saltan, *et al.* 2013). In order to have good achievement of chip seal, the limit for initial texture depth should not be less than 9 mm (Gürer *et al.* 2012).

1.2 PROBLEM STATEMENT

The issue of road accident have been a headline and reported by media. According statistics from Malaysian Institute of Road Safety Research (MIROS), there was a steady increase in the number of road crashes every year from year 1997 to 2015. In year 2014, the number of road crashes recorded at 476,196 crashes and increased to 489,606 crashes in year 2015. There was an increase of about 2.8% in a year.

There were many factors that influenced road crashes where weather conditions, road users behaviour and pavement characteristics were the most significant factors. Other than that, pavement characteristics which included geometry design of pavement, stop-over distance and skid resistance were also part of the well-known factors. Study shown that there was an increase in number of road crashes when skid resistance number decrease (Al-mansour & G 2006). Skid resistance is the friction between pavement and tire. The higher the number of skid resistance, there was stronger gripping effect between pavement and tire. The lower the number of skid resistance, the lower the ability of the driver to control vehicle.

In pavement, microtexture played a role when vehicles in low speeds whereas macrotexture played a role when vehicles in high speeds (Stroup-gardiner 2001). Since most of the crashes were also related to speeding activity, this research aims to focus on macrotexture in order to help reducing the number of crashes in future years.

Any road pavement was initially designed for a specific amount of skid resistance. When time passed a period of time, skid resistance number will decrease. In order to maintain the skid resistance number significantly on pavement, a research need to be done to study the influence of macrotexture parameters in chip seal in order to prolong pavement performance.

1.3 RESEARCH OBJECTIVES

The main purpose of this research was to study the skid resistance performance enhancement. The objectives have been listed below in order to achieve the aim of this research.

1. To identify different Mean Texture Depth (MTD) of chip seals on asphalt concrete pavement samples using volumetric patch method.
2. To determine British Pendulum Number (BPN) of chip seals on asphalt concrete pavement samples using British pendulum test.
3. To analyze the optimum skid resistance of chip seal base on value of mean texture depth (MTD) and British Pendulum Number (BPN).

1.4 SCOPE OF RESEARCH

The scope of research involved the macrotexture parameter which was mean texture depth (MTD) in skid resistance. Researchers found that the microtexture characteristics of aggregate must be considered in examining macrotexture of pavement (Pancar & Karaca 2016). The results obtained would be different from ordinary way if microtexture characteristics was not in consideration (Pancar & Karaca 2016). Hence, the microtexture parameter which were aggregate polishing characteristics (harsh surface), aggregate texture and aggregate shape would be fixed throughout laboratory in this research.

In order to make sure the production of chip seal process was smoothly, Standard Specification for Road Works (Section 4: Flexible Pavement) prepared by Public Works of Malaysia (JKR 2008) was a guidance. Marshall mix method was used in this thesis and optimum asphalt content was 4.5%.

There was many variations of chip seal. In this research, only single chip seal variation was discussed in this research. The pavement surface condition was in a dry condition. The others condition such as oil, muddy, dust and grease were excluded in this research.

1.5 SIGNIFICANCE OF RESEARCH

Road safety is a crucial issue in transportation. One of the parameters was macrotexture on road pavements that can take significantly to affect road pavements skid resistance. This research found a way to improve skid resistance performance in terms of macrotexture parameter. As skid resistance performance increases, this will increase road safety level in this country. When there is reduction of accident occurs, government expenditure spends to handle traffic accidents will be less. Besides that, by getting optimum macrotexture parameters conditions and this will increase skid resistance in road pavements.

CHAPTER 2

LITERATURE REVIEW

2.1 SKID RESISTANCE

Skid resistance is the frictional force between tire and road pavements. It is crucial for road pavements to provide enough skid resistance from safety perspective. Skid resistance is an indicator of the pavement strength to resist the vehicles tires from skidding (Kuttesch *et al.* 2004). Skidding will occurs when the frictional between pavement and vehicles tires was not enough to afford the frictional required (Kennedy *et al.* 1990). Low level of skid resistance exist on road pavements, there is prone to occurs accident (Georgiou & Loizos 2014).

For road pavements, the element to exist frictional force is on top surface. The parameters of top surface aggregate has been studied by researchers. Georgiou & Loizos (2014) studied that the parameters of top surface aggregate and its affect towards the fictional force performance. The parameters of aggregate that Georgiou & Loizos (2014) considered that were different aggregate sizes, mix gradations and binder content. The factors that affected the pavement friction by researchers were summarized as shown in Table 2.1 (Mataei *et al.* 2016).

Table 2.1: Factors which affecting pavement friction

Pavement Surface Characteristics	Vehicle Operating Parameters	Tire Properties	Environment
• Microtexture • Macrotexture • Megatexture • Unevenness • Material properties • Temperature	• Slip speed - Vehicle speed - Braking action • Driving maneuver - Turning - Overtaking	• Foot print • Tread design and condition • Rubber composition and hardness • Inflation pressure • Load • Temperature	• Climate - Wind - Temperature - Water (rainfall, condensation) - Snow and ice • Contaminants - Anti-skid material (salt, sand) - Dirt, mud, debris

Adapted from: Mataei *et al.* (2016)

There were seasonal weather factors to affect skid resistance performance. Kuttesch *et al.* (2004) found that the skid resistance on pavements performed better in cold weather or winter compared to summer. During winter season, the salts inside ice melting and this phenomenon will polishing the aggregate resulting that the skid resistance performance (Jayawickrama *et al.* 1996). During winter season, the water retain most of the time on pavements, it was believed that water acted as lubricants to prevent aggregate from polishing (Jayawickrama *et al.* 1996). Moreover, during heavy rainfall precipitation, the rain water tended to flush away small particles inside drainage route of pavements resulting to increase macrotexture depth of pavement. Hence, short term of skid resistance performance increase too (Hill & Henry 1982). Meanwhile, the tires will be deformed during summer season, this caused the frictional between tires and pavement decreased (Jayawickrama *et al.* 1996).

Researchers found that water, clay, dust, dry sand, oil and grease were the factors to cause skidding on pavement (Harish *et al.* 2013). Harish *et al.* (2013) concluded that dry sand and oil play a role which was lubricating materials and resulting low macrotexture depth. The present of dry sand and oil were to prevent the macrotexture depth to develop satisfactory skid resistance. Although the pavement with satisfy macotexture depth but contained dry sand showing that no contribute on skid resistance at all (Harish *et al.* 2013). The most practical way was to keep road pavement free from any impurities at the time.

There were two methods to indicate pavement friction characteristics in laboratory works which were British pendulum tester and dynamic friction tester. The advantage of these two testers were convenience to carry and easy to operate. In this research, it was more focus on British pendulum tester. For British pendulum tester, it was measuring the difference of pendulum height before and after, and this difference able to interpret the friction pavement characteristics (Henry 2000). Saito *et al.* (1996) found that there was a disadvantage for British pendulum tester which was the outcome of British pendulum tester was not strongly correlated with others frictional measurement devices due to British pendulum tester was a low speed friction measurement.

2.2 CHIP SEAL

Chip seal is a layer that embed aggregate with specified pavement surface characteristics on the top layer of road pavement which is wearing coarse. Chip seal is involved hot spray of binder which is applied and aggregate is distributed evenly over binder. This chip seal not only can be applied on poor skid resistance performance of road pavement to restore skid resistance, it can be done on new pavement also (JKR 2008). The expected performance of single chip seal was about 4 to 6 years whereas 5 to 7 years for double chip seals (Pierce & Kebede 2015).

The pavement surface treatment for asphalt pavement was binder-aggregate seal. There was consists of many types of binder-aggregate seal which were single chip seal, double chip seal, cape seal and sand seal (Praticò *et al.* 2015). These binder aggregate seal as asphalt emulsion and spraying on existing road pavement. However, choosing the suitable type of binder-aggregate seal was crucial for economic aspect. Sand seal acted as a replacement for chip seal when there was shortage of chip seals. This was due to the aggregate of chip seal was not economical compared to sand seal (Praticò *et al.* 2015). The variations of chip seal were illustrated as shown in Figure 2.1.

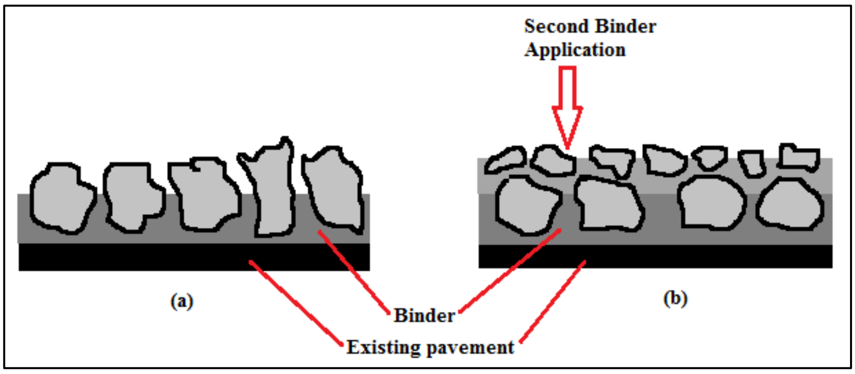

Figure 2.1(a): Single chip seal, **Figure 2.1(b):** Double chip seal

There was relationship between aggregate sizes with traffic volume. The heavier the traffic volume, the bigger aggregate size used for chip seal (Praticò *et al.* 2015). To modify the framework of real road pavements, Li & Liu (2011) proposed to do a layer plate which was asphalt concrete underneath chip seal. The dimension of pavement sample used by Li & Liu (2011) is 300 mm × 300 mm × 45 mm.

Applying the suitable amount of binder also crucial in road pavement construction. Excessing of binder application on pavement would causing bleeding (Li & Liu 2011). In Li & Liu (2011) study, the type of spraying binder using was modified emulsified asphalt binder.

There were 2 types of aggregate in Li & Liu (2011) study, which were basalt and limestone. The diameter of basalt varied from 3 – 5 mm whereas the diameter of limestone varied from 5 – 10 mm. According Standard Specification for Road Works (JKR 2008), the sizes of chip seals should be retained on 5 mm sieves. From Pierce (2015) study, the aggregate gradation of chip seals varied from 0.375 – 0.625 in. (approximately 9.53 – 15.88 mm). The chip seal aggregate sizes varied from 4.0 – 7.5 mm in previous study (Praticò *et al.* 2015).

Applying with correct type of rollers also needed to be considered. Li & Liu (2011) discussed that roughly all chip seal was normally using pneumatic roller. There was needed to take extra care on the pavement samples when using steel-wheel roller, this was due to its behaviour that can destroy aggregate. Li & Liu (2011) studied that the purpose of using roller was to make sure the orientation of aggregate correctly embedded with binder. There was allocation of rubber layer with 15 mm thickness above pavement sample when applying rigid wheel roller, this was to make sure the outcome of pavement sample was in good quality (Li & Liu 2011).

Georgiou & Loizos (2014) investigated that the laboratory testing location should be the centre of the pavements. This was the reason due to segregation occurs at the side of road pavements. In Georgiou & Loizos (2014) research, the pavements sample using was square steel mould with dimension 305 mm × 305 mm × 50 mm. There were 2 factors that affected the mean texture depth in Georgiou study which were binder content and air voids.

In Georgiou & Loizos (2014) study, a segmented roller compactor was adopted in his study. From Georgiou & Loizos (2014) observation, the gyratory compactor was not encouraged to be used in laboratory samples. The results of laboratory was not fully correlated with field result after using gyrator compactor. This was due to the orientation of chip seal aggregate particles was different from field compactor equipment when chip seals pavement sample using gyratory compactor.

2.3 MACROTEXTURE

This research was more focus on pavement-related factors which was macrotexture of pavements for skid resistance performance. Macrotexture is about the particles size arrangements, shape and size of aggregates. These aggregate parameters affected skid resistance performance (Stroup-gardiner 2001). Macrotexture played a significant role when pavement was wet when compared the pavement in dry condition (Harish *et al.* 2013). Macrotexture also acted a role which was to drain water out when pavement was wet (Kotek & Florková 2014). The irregularities of aggregate to create spaces for the water to escape thus increase skid resistance performance of pavements.

Roe *et al.* (1991) studied that the range of macrotexture depth in between 0.2 mm to 3.0 mm. Another researcher studied that macrotexture depth start from 0.5 mm (Balmer & Hegmon 1980). In Tighe *et al.* (2000) study, the macrotexture depth varied from 0.2 – 3.0 mm. The macrotexture range of aggregate was illustrated as shown in Figure 2.2.

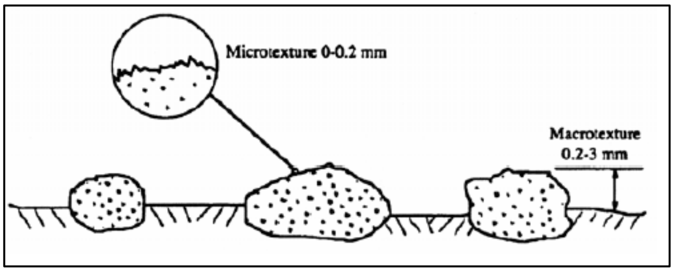

Figure 2.2: Example of microtexture and macrotexture

Source: Tighe *et al.* (2000)

From study of TNZ (1981), the pavement considered as failure when mean texture depth (MTD) was less than 0.7 mm when the vehicles speed was less than 70 km/hr and considered as failure when MTD was less than 0.9 mm when the vehicles speed was more than 70 km/hr.

Praticò *et al.* (2015) proposed macrotexture modeling to predict the relationship between macrotexture and mix design. The element of mix design included aggregate gradation and amount of asphalt binder. In Praticò *et al.* (2015) study, there was still undetermined results between the relationship between macrotexture and mix design. There was need for a more detail macrotexture modeling to predict more precise results.

There were three common techniques to identify macrotexture characteristics of pavement which were profilometers, volumetric and outflow (Kuttesch *et al.* 2004). For profilometers technique, it was using lasers to produce two dimensional measure of pavement macrotexture characteristics. For volumetric technique, it was spreading known sand particles sizes with specified amount on pavement to get macrotexture parameter. The macrotexture parameter of mean texture depth (MTD) can be obtained by calculation. Sand patch test usually was carried out for this techniques according ASTM Standard Measuring Pavement Macrotexture Depth Using a Volumetric Technique (ASTM E965 1996). For outflow techniques, the time taken was recorded for known water volume flowed out from cylinder which was located above pavement (Wambold *et al.* 1995). In conclude, sand patch test and British pendulum test were normally the test that were using to interpret the pavement texture characteristics (Mataei *et al.* 2016).

One of the macrotexture parameters is mean texture depth (MTD). Mean texture depth (MTD) is the texture depth of chip seal aggregate that laid on pavement.

Researchers mentioned that the minimum MTD required for new asphalt concrete pavement was 1.5 mm (Roe & Lagarde-Forest 2005). Another researchers analysed that the maximum MTD value required was 1.8 mm and it was acceptable for every circumferences (Ahammed & Tighe 2008). The requirement minimum of MTD should considered every factors which were including traffic volume, concrete mix materials and regional climate (Ahammed & Tighe 2008).

Researchers found that there was a strong relationship which was $R^2 = 0.97$ between the results of MTD with sand patch test and mean profile depth (MPD) with 3D laser scanning (Sengoz *et al.* 2012). Sengoz *et al.* (2012) concluded that sand patch test gave a correct judgement of pavement texture.

2.4 BINDER CONTENT

For binder content, Georgiou & Loizos (2014) varied the binder content from 4 – 6 %. Georgiou & Loizos (2014) discovered that the British Pendulum Number (BPN) decreased with an increasing of binder content provided that temperature maintained at $20\,℃$. Georgiou & Loizos (2014) observed that increasing binder content resulting decreasing mean texture depth. This can be shown by Georgiou study result that was 4.5% of binder content showing the best frictional performance among others binder content variations. On the other hand, 6% of binder content showing the poorest frictional performance.

2.5 SAND PATCH TEST

Sand patch test is commonly used to measure for macrotexture parameters. However, it was not the most precise result shown from sand patch test (Fisco 2009). This was due to sand patch test carried out by human, there was always possible variation from result. It was encouraged that sand patch test was carried out by a professional technician who he or she does sand patch test as his or her part of job daily (Fisco 2009).

Sand patch test is using certain amount of glass spheres to pour on center point of road pavements, proceeds by using spreading tools to form a circular in shape provided uniformly distributed. The diameter was recorded three to four times and average of diameter of circular sand were collected. By using formula, the mean texture depth

(MTD) was determined. The formula was stated in ASTM E965 (1996) and was expressed as in Eq. (2.1)

$$MTD = \frac{4 \cdot V}{\pi \cdot D^2} \tag{2.1}$$

where V = volume of glass beads spreading in mm^3,

D = diameter of circular sand in mm.

The aggregate sizes that are using for sand patch test was 90% of sand passing 0.25 mm sieve and retained on 0.125 mm sieve (Xiao *et al.* 2013). The diameter of circular sand showed inversely proportional relationship to the mean texture depth (MTD). The bigger of the diameter of sand circle, the lower the mean texture depth.

TNZ (1981) proposed the sand particles between 0.297 – 0.595 mm (between No. 50 and No. 30 sieve sizes) in sand patch test. TNZ (1981) used 2.75 in^3 (approximately 45.1 ml) of sand in order to get the mean texture depth of pavements after 12 months construction.

The sand particles used was the sand particles between 0.150 – 0.300 mm which was the sand particles passing 300 microns sieve and retained on 150 microns sieve (Harish *et al.* 2013).

Fisco (2009) discussed that the volume of glass bead with 25 ml was used for his studies. However, Fisco (2009) discovered that 25 ml of glass beads was too many in volume for certain samples, Fisco (2009) tried to reduce from 25 ml to 12.5 ml of glass beads volume. There was one more reduction to 5 ml of glass beads for that 12.5 ml of glass beads was too many in volume.

When pouring sand on the surface of pavements, the sand should distributed evenly and to form a circular shape. It was to ensure the sand cover all the chip seals aggregate, the abnormal sizes of aggregate can be ignored when pouring the sand on pavements as shown in Figure 2.3.

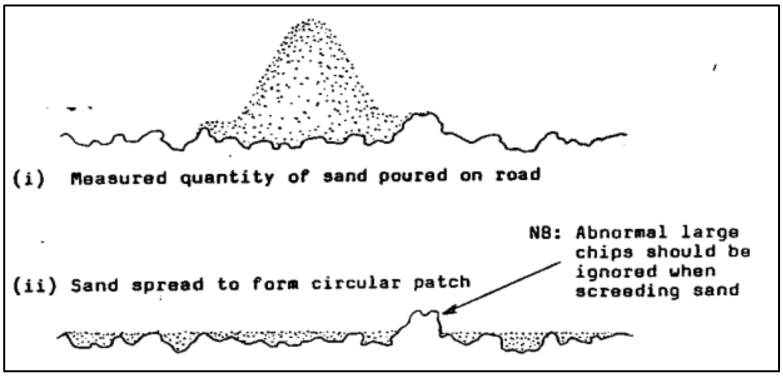

Figure 2.3: Sand patch test

Source: TNZ (1981)

2.6 BRITISH PENDULUM TEST

In British Pendulum Test, the apparatus used was British pendulum tester. By using this test, it was applied both field and laboratory tests. For field test, it was applied to flat surfaces whereas curved surfaces for laboratory specimens.

There is a pendulum on British pendulum tester, at the end of pendulum of tester, there is a rubber slider attached on it. When pendulum was released from a fixed height, the rubber slider passed through road pavements. British Pendulum Test was the energy loss when rubber slider pass through the road pavements (ASTM E303-93 2003). There was kinetic energy loss when rubber slider passed through road pavements (Georgiou & Loizos 2014). The results shown was the British Pendulum Number (BPN) which was the conversion of kinetic energy and lost to frictional force (Georgiou & Loizos 2014). This frictional force shown by BPN which showing the skid resistance performance of road pavements.

In Georgiou study, the pendulum applied in longitudinal and lateral both ways in pavements sample. The results shown that there was no much difference in terms of BPN value. The standard mentioned that four pendulum swings was required for each tested surface (ASTM E303-93 2003). The BPN values at each point were taken for five times and the average BPN values were obtained for results (Charles *et al.* 2006). However, the measurement of BPN value was not available to evaluate the accuracy of result, the only way to achieve precision of result was to repeat test until BPN measurement value was kept constant (ASTM E303-93 2003). Researchers took mean of five consecutive BPN value during conduct BPN measurement (Harish *et al.* 2013). It was to note that the five consecutive BPN value does not vary from three units.

For road pavement skid resistance, it is depends on tired-related factors and pavement-related factors. However, Lu *et al.* (2006) found that unmanageable climate factors which was temperature did affect the skid resistance performance. This was due to the material characteristics of pavement bituminous binder and rubber slider on British pendulum tester were viscoelastic (Lu *et al.* 2006). There was a tendency which was the skid resistance performance was decreasing in hot weather whereas well skid resistance performance in cold weather (Bazlamit *et al.* 2005). Due to road pavement bituminous binder and rubber slider were temperature dependent, a temperature correction factor should be applied on test result when applying British pendulum tester (Lu *et al.* 2006).

Researchers mentioned that the material of slider stated in ASTM E303-93 (2003) was natural rubber which was temperature dependent (Lu *et al.* 2006). The temperature correction factor was summarized as shown in Table 2.2. Researchers maintained samples at 20 ± 1 ℃ temperature and pendulum testing at samples surface controlled at 20 ± 1 ℃ temperature (Karaca *et al.* 2013). Tighe *et al.* (2011) carried out laboratory works with temperature at 20℃ to collect BPN values.

Table 2.2: Temperature corrections for BPN readings using the Transport Research Laboratory rubber slider

Surface Temperature (℃)	**Correction Factor (BPN units)**
8 to 11	-3
12 to 15	-2
16 to 18	-1
19 to 22	0
23 to 28	+1
29 to 35	+2

Source: Lu *et al.* (2006)

Researchers found that the aggregate shape did affect the BPN values (Shah & Abdullah 2010). Shah & Abdullah (2010) discovered that angular aggregate showing the greater skid resistance performance whereas elongated and flaky aggregates showing the poorest skid resistance performance.

Researchers found that with increasing groove width, the BPN value increased too for dry transverse and longitudinal grooved surfaces provided that constant groove spacing and depth (Pancar & Karaca 2016). This can be interpreted that with increasing groove width, this was same meaning that increasing mean texture depth of marcotexture parameter. Researchers found that one of the factor to get desired pavement friction was texture depth (Tighe *et al.* 2011). In Tighe *et al.* (2011) study, the result showed that both macrotexture and microtexture affected BPN values. Moreover, most of the researches mentioned that microtexture of pavement affected the result of British pendulum tester, macrotexture played a role on measurement of British Pendulum Number (Fwa *et al.* 2003). Fwa *et al.* (2003) and Liu *et al.* (2004) presented that the macrotexture of pavement was one of the factor that affect British Pendulum Number.

On the other hand, researchers mentioned that British pendulum tester had weaknesses such as British Pendulum Number can be affected by the steps which the person to conduct it and showed wide inconstancy (Mataei *et al.* 2016). Additionally, British pendulum tester showing a frictional property of pavement in a low speed (Saito *et al.* 1996).

2.7 SUMMARY

This chapter presented a general concept of skid resistance from previous researchers study. The perception on skid resistance had been reviewed in section 2.1. In this section, the factors that affected skid resistance performance had been analysed and categorized. In the next section, the variation of chip seal had been revised in section 2.2. The requirement of chip seal and the laboratory preparation had been discussed. The characteristics of macrotexture had been reviewed in section 2.3. The range of marcotexture and the measures to identified macrotexture parameters had been explained. The optimum binder content that researchers considered had been revised in section 2.4. One of the test was reviewed which was sand patch test in section 2.5. In this section, the requirement to carry out sand patch test had been expressed. Another test was British pendulum test was revised in section 2.6. That was some precautions needed to be concerned the outcome of the test which was British Pendulum Number (BPN) had been elaborated.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the procedure to prepare asphalt concrete pavement samples was discussed. Next, pavement samples proceeded to brushing of binder and spreading of chip seal. Then, chip seal specimen readied for testing. The detailed description was included in section 3.2.

There were 2 divisions for macrotexture measurements which were static measurements and dynamic measurements (Meegoda & Gao 2015). For static measurements which was volumetric patch method was used to determine mean texture depth (MTD) of each sample in laboratory. The procedure was explained in section 3.3.

After conducting volumetric patch method, samples were tested the skid resistance performance. The operation of British pendulum test was recorded in section 3.4. By conducting British pendulum test, the result of skid resistance of samples were determined.

3.1.1 Flow Diagram for Methodology

This subchapter described the whole methodology of thesis. In order to complete thesis, the steps discussed below were followed as shown in Figure 3.1.

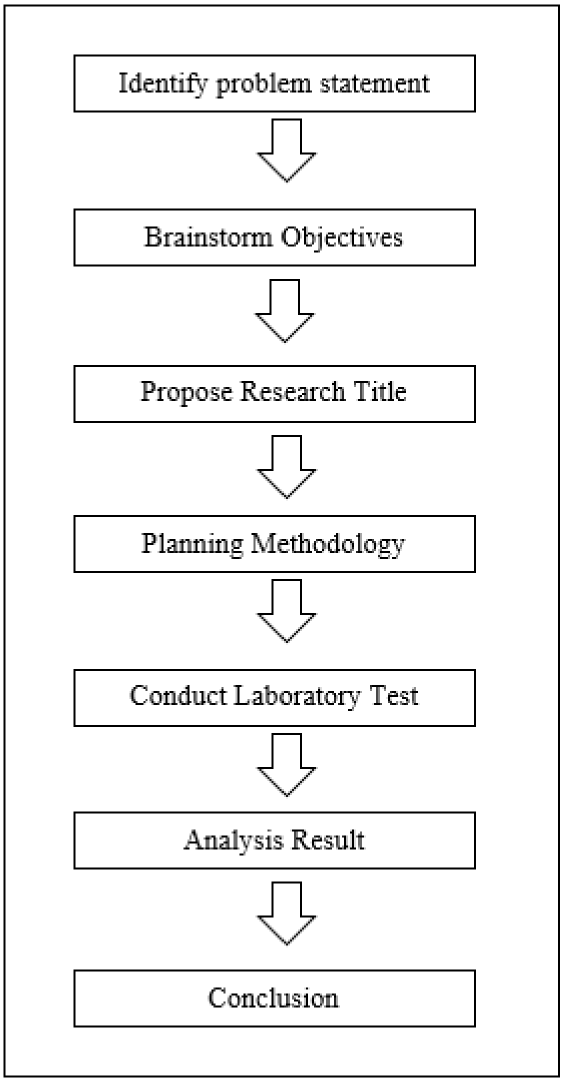

Figure 3.1: Flow diagram for methodology

From Figure 3.1, the initial element that needed to determine was problem statement. In order to solve the problem statement, some objectives were decided. From the idea of problem statement and project objectives, research title was proposed. Next, methodology were planned and laboratory tests were carried out. The last stage proceeded was analysing result and conclusion was made for this project.

3.1.2 Flow Diagram for Laboratory Work

This subchapter described each methodology in order to achieve objectives. There was some stages of laboratory works were carried out as shown in Figure 3.2.

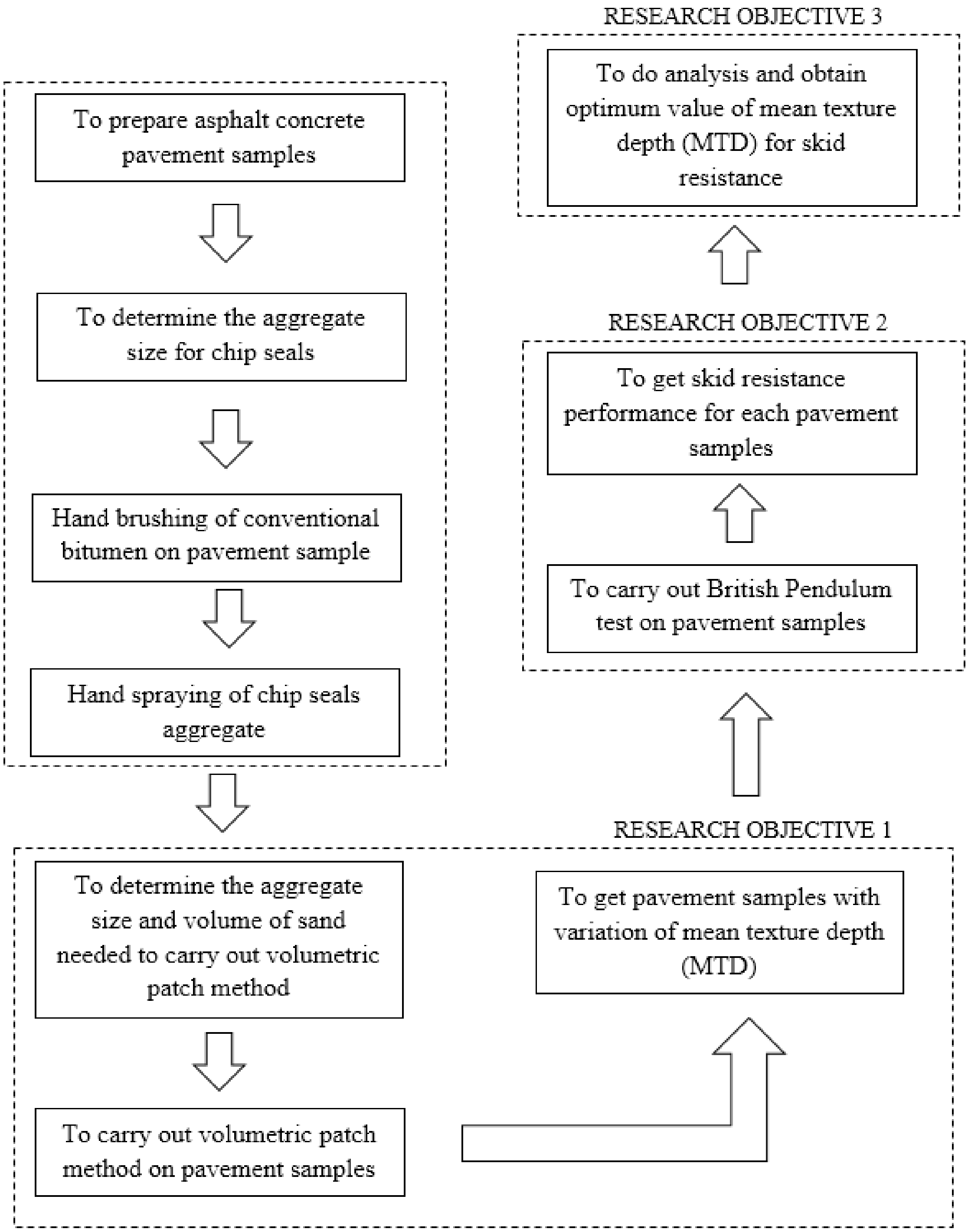

Figure 3.2: Flow diagram for laboratory work

From Figure 3.2, there was preliminary stage before achieving research objective 1. The preliminary stage was preparation of chip seal on asphalt concrete pavement samples. During this stage, asphalt concrete pavement samples were prepared, aggregate size for chip seal was determined, conventional bitumen was hand brushed on pavement samples and chip seal aggregate was hand sprayed.

In order to achieve research objective 1, aggregate size and volume of sand were determined. Volumetric patch method was carried out on pavement samples and variation of mean texture depth (MTD) were obtained for each samples. Next, some measures were conducted to complete research objective 2. British pendulum test was carried out on pavement samples and British Pendulum Number (BPN) were identified for each samples. To accomplish research objective 3, optimum value of mean texture depth (MTD) was recognized for optimum skid resistance performance and analysis were done.

3.2 PREPARATION OF CHIP SEAL ON ASPHALT CONCRETE PAVEMENT SAMPLES

3.2.1 Preparation of Asphalt Concrete Pavement Samples

The asphalt concrete pavement sample were prepared according to Marshall mix design method. The type of mix for the asphalt concrete pavement sample was wearing course (AC 14).

Firstly, the aggregates needed for asphalt concrete pavement samples were taken from store. The big tray and trolley were used to deliver the aggregate from store to highway laboratory for sieve analysis. Then, shovel was used to deliver the aggregate from store to big tray. Aggregates were taken from store by using shovel and were transferred into big tray as shown in Figure 3.3. Next, the aggregates were transferred to the sieve that was arranged before according the order of sieve size. The sieve size with 20 mm was located at the top of the size shaker, following by 14 mm, 10 mm, 5 mm, 3.35 mm, 1.18 mm, 0.425 mm, 0.150 mm and 0.075 mm. The arrangement of sieve size were arranged in order as shown in Figure 3.4. The purpose of aggregates that went through sieve analysis was to separate the aggregate by their size categories.

Figure 3.3: Delivering aggregates from store

Figure 3.4: Sieve shaker

The weight of each asphalt concrete pavement sample was 1138 g. The sieve analysis was conducted until the weight of each categories of aggregate size was sufficient from calculation. The each categories of aggregate sizes were stored at respectively container with labelled each categories of aggregate size. The calculation of pavement sample that the weight needed to be prepared as shown in Table 3.1.

Table 3.1: Calculation of pavement sample for wearing course (AC 14)

Sieve size (mm)	**Passing by weight (%)**	**Selected gradation (%)**	**Percentage of weight of aggregate (%)**	**Weight of aggregate (g)**
20	100	100	0	0
14	90 – 100	95	5	56.90
10	76 – 86	81	14	159.32
5	50 – 62	56	25	284.50
3.35	40 – 54	47	9	102.42
1.18	18 – 34	26	21	238.98
0.425	12 – 24	18	8	91.04
0.150	6 – 14	7	11	125.18
0.075	4 – 8	4	3	34.14
Cement	-	-	4	45.52
Total	-	-	100	1138.00

Secondly, the weighted 1138 g of aggregate and cement with correct proportion for each asphalt concrete pavement sample were put in small try. The small tray together with aggregate and cement were delivered to oven with temperature of 130℃. This was to ensure that aggregate and cement contain no any moisture before mixing process. The aggregate and cement were put in oven at least one day.

Thirdly, there was preparation of bitumen. The hot knife was needed to take bitumen from drum. The amount of bitumen needed for research was obtained from calculation which was done before. The binder content maintained at 4.5% which shown the optimum skid resistance performance (Georgiou & Loizos 2014). For this research, 53.63 g of bitumen was required for each pavement sample. The total needed of bitumen was transferred to small steel container before storing in oven. The bitumen needed was stored in oven at least 2 hours with temperature of 120℃.

Next, there was mixing process for aggregate, cement and bitumen. Both aggregate and bitumen were taken out from oven for mixing process. Thermometer was used to measure the temperature of aggregate, this was important to make sure that the temperature of aggregate was maintained. The aggregates were relocated from small tray to mixer. The mixer with aggregate were put on balance to measure the weight of bitumen needed for each sample. During mixing process, it was crucial to ensure that all aggregate particles were mixed well and coated with bitumen. This was because the function of bitumen was to stick each of the aggregate particles together. After mixing process was done, the aggregate were transferred from mixer to mould. The filter paper was brushed with oil and were put at the top of base plate of compaction mould. Hand gloves were worn all the way when handling mould to protect hand from high temperature.

Then, the mould filled with aggregate were sent to compaction. The sample was put in compactor for compaction. There was 75 blows required for each surface of asphalt concrete pavement sample. After the top surface of surface was done for compaction, the extension collar was taken out and the mould was turned the upside down for compaction of another surface. The mould was stored at room temperature for the purposes of cooling down of sample. The sample was extruded by using hydraulic jacking device.

3.2.2 Determination of Aggregate Sizes of Chip Seal

Based on the previous study (Li & Liu 2011, JKR 2008, Pierce 2015, Praticò *et al.* 2015), the aggregate sizes of chip seal was the aggregate that retained on 10 mm of sieve sizes.

3.2.3 Brushing of Binder

The bituminous binder used was conventional bitumen with grade 80 – 100 as shown in Figure 3.5 (JKR 2008).

Figure 3.5: Conventional bitumen with grade 80 – 100

Before taking bitumen out from drum, a pair of hand glove was required to wear. Hot knife was required to cut bitumen and bitumen was transferred to small steel container. The small steel container was put in oven for the purpose of heating of bitumen. This was to ensure the homogeneity of bituminous binder. When the bitumen was in viscous condition, the bitumen was ready for brushing of binder. A layer of bituminous binder was hand brushed by using brush. During brushing of binder, it was needed to make sure bitumen was in sticky condition. This was to ensure that chip seals aggregate was able to stick with bitumen. The asphalt concrete pavement sample was directly proceeded to next step which was spreading chip seal.

3.2.4 Spreading of Chip Seal

After done brushing bitumen, the spreading of chip seal aggregate were done on bituminous layer by hand spreading. It was needed to take note that the surface of bituminous binder was covered completely with aggregates. The surface of bituminous binder was covered completely with aggregates as shown in Figure 3.6.

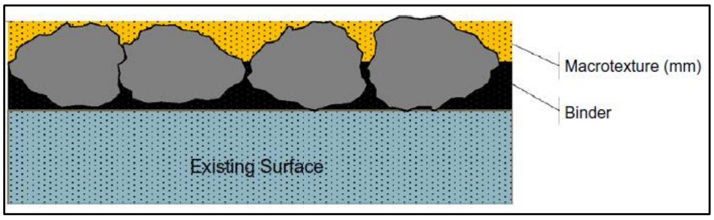

Figure 3.6: Single chip seals

Source: Aktaş, Karaşahin & Tiğdemir (2013)

Next, the pavement sample had left for 4 hours and continued for volumetric patch method and British pendulum test (JKR 2008).

3.3 VOLUMETRIC PATCH METHOD

3.3.1 Test Method

Volumetric patch method is using a fixed amount of sand and pouring sand covered with an area on the pavement sample (Labbate 2001). Before starting volumetric patch method, it was crucial to make sure the surface of pavement sample was clean and free from any impurities which included sand, dust, water and oil grease. From previous study (Xiao *et al.* 2013, Harish *et al.* 2013, Fisco 2009), 3 ml of sand particle size of 0.150 mm were used for volumetric patch method.

Initially, the fixed amount of sand (3 ml) with sand particle size of 0.150 mm was filled in measuring cylinder. Next, sand was poured in the centre part of pavement sample, the sand was spread from centre part to form a circular area by using spreading tools. The sand was poured in circular shape as shown in Figure 3.7.

Figure 3.7: Asphalt concrete pavement sample undergoes volumetric patch method

After done volumetric patch method, the value of mean texture depth was calculated. This could be done by using ruler and recording the diameter of the spreading sand on pavement sample. To get mean texture depth for each sample by using formula which is expressed as in Eq. (4.1)

$$Mean\ texture\ depth\ (MTD) = \frac{4 \cdot V}{\pi \cdot D^2} \tag{4.1}$$

where V = the volume of sand used in mm^3,

D = the diameter of the circular sand on pavement sample in mm.

3.3.2 Material and Apparatus

To conduct volumetric patch method, some materials were needed. The materials were 3 ml fixed amount of sand with particle size (0.150 mm) for each sample. For apparatus part, stiff wire brushes for surface cleaning, 10 ml measuring cylinder to fill with sand, spreading tools and 500 mm (12 inch) ruler to measure the length and width. To increase the accuracy of volume of sand filled, a laboratory balance was used to ensure the weight of sand to be poured for each samples was the same (Labbate 2001). The balance was used throughout laboratory works as shown in Figure 3.8.

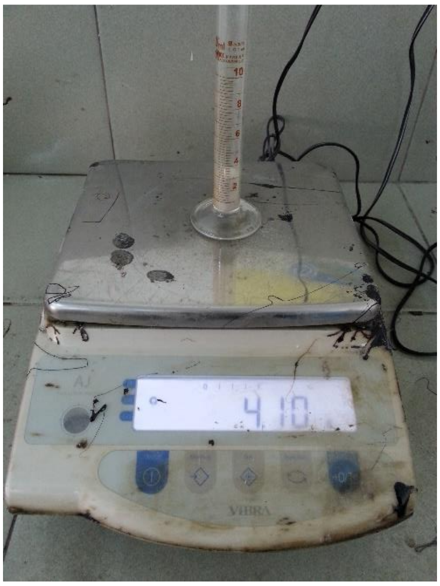

Figure 3.8: The weight of measuring cylinder with sand was measured

3.4 BRITISH PENDULUM TEST

3.4.1 Test Method

British pendulum test is a test to get the value of British Pendulum Number (BPN). Before using British pendulum tester, several measurement were taken to ensure that the British pendulum tester was in good condition. It was important to do levelling of British pendulum tester. Firstly, the British pendulum tester was levelled accurately by turning levelling screws. This could be confirmed that British pendulum tester was levelled accurately by observing the bubbles was in the centre of spirit level.

Secondly, there was zero adjustment for British pendulum tester. It was required to check that the pointer was paralleled to the pendulum arm. It could be done by turning the pointer until it came up against the pointer stopped. The pointer tip was in line with the mark on the scale plate. Next, the arm was replaced in the catch block and turned the pointer anti-clockwise until it came up against the pointer stopped. Now, British pendulum tester readied for zero adjustment. Before pressing the release button, British pendulum tester was ensured that there was no blockage when pendulum arm was swinging. At the moment, the position of the pointer tip was observed on the scale plate. If the pointer tip was not in line with the zero mark, the friction pads was adjusted by turning the locking rings. To increase the pressure by turning locking rings clockwise and to decrease the pressure by turning locking rings anti-clockwise. The steps were repeated until the pointer stopped at the zero mark on scale plate. At least three consecutive swings were required that pointer stopped at the zero mark.

Thirdly, there was slide length adjustment. Initially, the arm height was set so that contact length was approximately correct. By using adjustment knob, height of pendulum arm was adjusted. In order to avoid slider had contact with surface, it had done by lifting handle and moved the pendulum arm to right hand side. Next, the pendulum arm was positioned so that slider rested on the surface gently.

Therefore, British pendulum tester readied to conduct the test. The pendulum arm was placed in the catch block and the pointer was rotated anti-clockwise against the pointer stop. Before testing asphalt concrete pavement samples, it was important to ensure surface of pavement samples was clean and free from any impurities (ASTM E303-93 2003). Moreover, the samples were held firmly due to force of pendulum might be pushed away the samples (ASTM E303-93 2003).

To start testing, the release button was pressed and the pendulum arm was caught on return swing before the slider hitting surface. When the pendulum arm was positioned to its starting position, the slider was lifted upwards with lifting handle to avoid slider contacted with pavement samples. The BPN value was observed and recorded that pointer’s position which showed on scale plate. The step was repeated by locating pendulum arm to the catch block until the results were satisfactory.

Six values were needed to get from British pendulum tester in order to increase the precision of the result. To avoid any errors to occur in laboratory test, these six values should be in constant.

3.4.2 Machinery and Apparatus

In British pendulum test, the machinery needed was British pendulum tester together with pavement samples. There was precaution needed to take note which was spirit level of British pendulum tester should be in centre position. The British pendulum tester that used throughout laboratory works as shown in Figure 3.9.

Figure 3.9: British pendulum tester

3.5 SUMMARY

This chapter presented a whole idea to conduct laboratory works. The overall methodology which included problem statement, objectives, research title, methodology, result and conclusion had been summarized in section 3.1.1. The detailed laboratory work which included preliminary preparation works had been outlined in section 3.1.2. The preparation of chip seal on pavement samples had been discussed in section 3.2. In this section, the laboratory works included preparation of asphalt concrete pavement samples, determination of aggregate sizes of chip seal, brushing of binder and spreading of chip seal. Next, the test method of volumetric patch method had been described in section 3.3. The formula used to calculated mean texture depth was attached. The test method of British pendulum test had been outlined in section 3.4. Before conducting British pendulum test, levelling, zero adjustment and length adjustment of British pendulum tester had been carried out.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the outcome from methodology were achieved the research objectives. Volumetric patch method was conducted and the value of mean texture depth (MTD) was identified. Result from volumetric patch method was reviewed in section 4.2. British pendulum test was carried out and the British Pendulum Number (BPN) was determined. Result from British pendulum test was discussed in section 4.3. The relationship between mean texture depth (MTD) and British Pendulum Number (BPN) was explained in section 4.4. The optimum value of MTD was obtained in this research.

4.2 MEAN TEXTURE DEPTH (MTD)

The data of mean texture depth was recorded after conducting volumetric patch test for 22 asphalt concrete pavement samples. There was 3 diameters of circular sand were taken and the average diameter was obtained. This was to ensure the diameter of circular sand was more proper to represent for each sample. The average diameter of 22 asphalt concrete pavement samples were collected as shown in Table 4.1. The average diameter was used for calculation of mean texture depth by using formula which was discussed in section 3.3. The mean texture depth of 22 asphalt concrete pavement samples was calculated as shown in Table 4.2.

Table 4.1: Average diameter of 22 asphalt concrete pavement samples

Sample	Diameter 1 (mm)	Diameter 2 (mm)	Diameter 3 (mm)	Average diameter (mm)
1	55	50	45	50.00
2	50	50	45	48.33
3	60	35	45	46.67
4	45	53	45	47.67
5	40	55	45	46.67
6	45	50	45	46.67
7	45	50	55	50.00
8	50	45	45	46.67
9	50	40	50	46.67
10	45	40	40	41.67
11	47	45	45	45.67
12	50	40	45	45.00
13	45	45	50	46.67
14	40	45	43	42.67
15	40	45	45	43.33
16	40	45	55	46.67
17	50	45	45	46.67
18	50	45	50	48.33
19	40	50	45	45.00
20	40	40	40	40.00
21	50	45	48	47.67
22	45	40	43	42.67

Table 4.2: Mean texture depth of 22 asphalt concrete pavement samples

Sample	Average diameter (mm)	Mean texture depth (mm)
1	50.00	1.53
2	48.33	1.64
3	46.67	1.75
4	47.67	1.68
5	46.67	1.75
6	46.67	1.75
7	50.00	1.53
8	46.67	1.75
9	46.67	1.75
10	41.67	2.20
11	45.67	1.83
12	45.00	1.89
13	46.67	1.75
14	42.67	2.10
15	43.33	2.03
16	46.67	1.75

Table 4.2: Continued

Sample	Average diameter (mm)	Mean texture depth (mm)
17	46.67	1.75
18	48.33	1.64
19	45.00	1.89
20	40.00	2.39
21	47.67	1.68
22	42.67	2.10

From Table 4.1, the diameters of circular sand varied from 35 – 60 mm. On the other hand, the variation of average diameter of asphalt pavement sample varied from 40.00 – 50.00 mm. It was shown that the average diameter of circular sand was necessary to calculation. This was because the range of average diameter was smaller when compared to diameters of circular sand. This was implied that the value of average dimeter was more significant to result of this laboratory. There were 8 samples recorded average diameter were 46.67 mm which was the mode for this data set.

From Table 4.2, the variation of mean texture depth (MTD) varied from 1.53 – 2.39 mm. The mode of this data set was 1.75 mm. From the value of average diameter, it could be analysed that the higher value of average diameter, the lower the MTD value. There was inversely proportional relationship between average diameter and MTD value. The high value of MTD could be explained that the chip seal aggregate arrangement was increasing groove width (Pancar & Karaca 2016). Increasing groove width has the same meaning that increasing mean texture depth, this could be explained that both held more fines aggregate particles during sand patch test. The more fines aggregate particles hold during sand patch test, the higher the value of mean texture depth. The result was compared with previous study as shown in Figure 4.1.

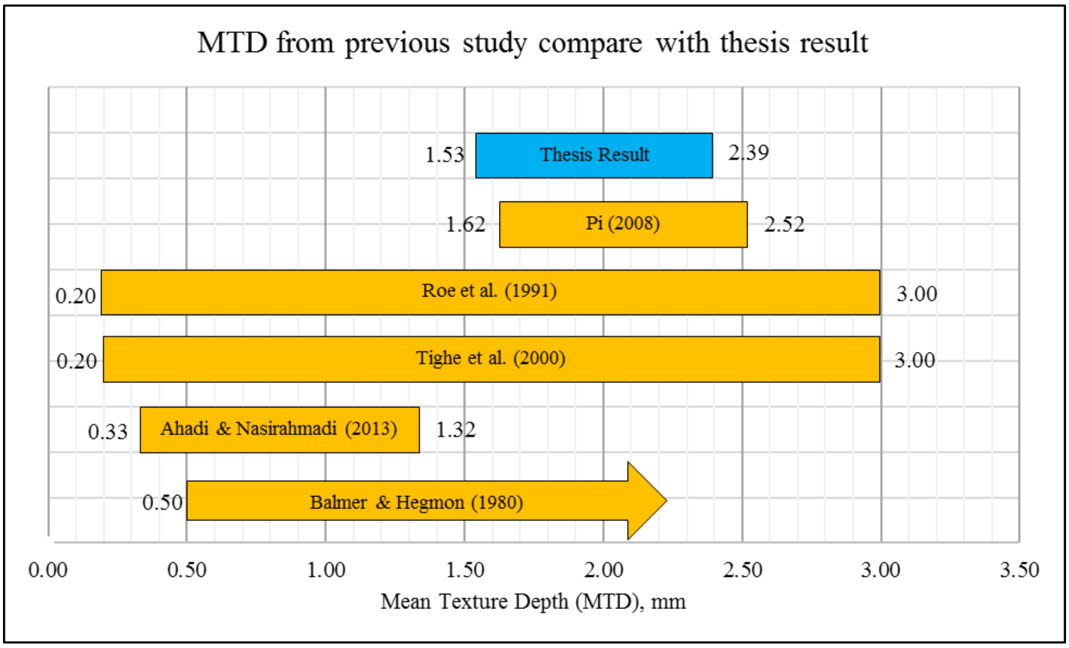

Figure 4.1: MTD from previous study compare with thesis result

From Figure 4.1, the MTD varied from 1.62 – 2.52 mm which was about the same with thesis result (Pi 2008). Roe *et al.* (1991) and Tighe *et al.* (2000) studied that the range of MTD in between 0.20 mm to 3.00 mm which shown that a quite wide range of macrotexture and exceeded thesis result range. According researchers result, MTD result recorded from 0.33 – 1.32 mm for dense grade No. 4 of asphalt pavement (Ahadi & Nasirahmadi 2013). Another researcher studied that MTD start from 0.50 mm (Balmer & Hegmon 1980).

To conclude previous study, the mean texture depth (MTD) in between 0.20 – 3.00 mm compared with this research which was between 1.53 – 2.39 mm. This was meaning that the data of mean texture depth (MTD) of this research was in the range.

4.3 BRITISH PENDULUM NUMBER (BPN)

After conducting British pendulum test, the data of British Pendulum Number (BPN) were recorded. There were 9 raw data for each asphalt concrete pavement samples and attached in **APPENDIX A**. However, 6 data were selected for calculation of average BPN, this was to avoid any errors to occur in laboratory test. The data of British Pendulum

Number (BPN) and average BPN of 22 asphalt concrete pavement samples was tabulated as shown in Table 4.3.

Table 4.3: British Pendulum Number (BPN) and average BPN of 22 asphalt concrete pavement samples

Sample	BPN 1	BPN 2	BPN 3	BPN 4	BPN 5	BPN 6	Average BPN
1	55	56	56	62	59	57	57.5
2	66	56	72	81	66	66	67.8
3	64	59	66	65	57	55	61.0
4	55	66	54	59	54	60	58.0
5	85	90	80	92	86	87	86.7
6	90	100	101	90	100	80	93.5
7	66	77	69	80	74	74	73.3
8	75	75	71	78	71	76	74.3
9	77	85	77	87	85	77	81.3
10	130	112	119	100	116	110	114.5
11	71	70	70	65	78	77	71.8
12	140	122	137	136	108	101	124.0
13	91	118	96	110	105	100	103.3
14	120	101	114	106	115	112	111.3
15	96	101	91	85	90	93	92.7
16	64	77	66	63	63	76	68.2
17	85	93	99	87	94	90	91.3
18	73	75	87	86	74	79	79.0
19	74	60	62	68	76	72	68.7
20	112	104	104	100	108	105	105.5
21	72	75	70	74	70	68	71.5
22	89	76	80	76	84	82	81.2

From Table 4.3, the value of BPN varied from 54 – 140. To obtain the precise result, 6 values of BPN were calculated the average BPN. The variation of average BPN of 22 asphalt concrete pavement samples varied from 57.7 – 114.5. It can be discussed the range of BPN and average BPN get were quite wider. The BPN of thesis result were categorized as good due to BPN value which was greater than 65 was categorized as good or excellent (Charles *et al.* 2006). The thesis result was compared with previous study as shown in Figure 4.2.

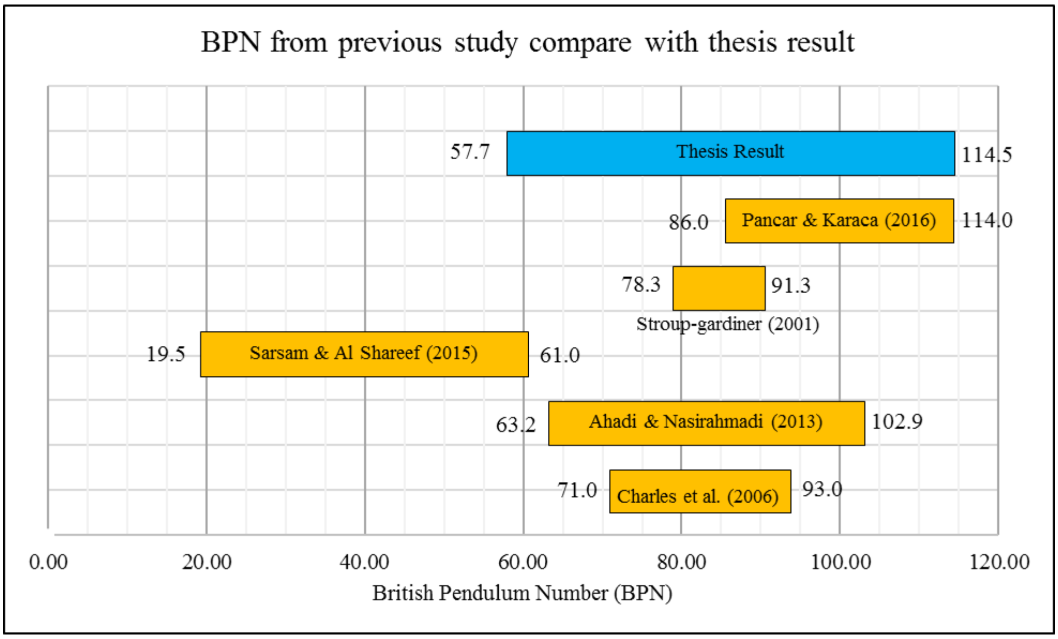

Figure 4.2: BPN from previous study compare with thesis result

From Figure 4.2, Pancar & Karaca (2016) recorded the BPN value from 86.0 – 114.0 for transverse and longitudinal grooved surfaces and this was within thesis result range. Researchers found that the mean BPN values recorded from 78.3 – 91.3 for dry samples and this was within thesis result range (Stroup-gardiner 2001). Another researchers recorded BPN values from 19.5 – 61.0 for asphalt concrete pavement with wet pavement surface and this range was not within thesis result range (Sarsam & Al Shareef 2015). Besides, researchers recorded the BPN values from 63.2 – 102.9 for asphalt pavements and which was about the same with thesis result (Ahadi & Nasirahmadi 2013). Researchers obtained results for dense concrete asphalt pavement with BPN values of 71.0 – 93.0 (Charles *et al.* 2006).

To conclude previous study, the British pendulum number (BPN) in between 19.5 – 114.0 compared with this research which was varied from 57.7 – 114.5. This was meaning that the data of British Pendulum Number (BPN) of this research covered the range of previous study.

4.4 CORRELATION OF MEAN TEXTURE DEPTH (MTD) AND BRITISH PENDULUM NUMBER (BPN)

The relationship between mean texture depth (MTD) and British Pendulum Number (BPN) was discussed in this section. The combination data of the mean texture depth were tabulated as shown in Table 4.4 which was extracted from Table 4.2 and British Pendulum Number which was extracted from Table 4.3.

Table 4.4: Mean texture depth (MTD) and British Pendulum Number (BPN) of 21 asphalt concrete pavement samples

Sample	**Mean texture depth (mm)**	**Average BPN**
1	1.53	57.5
2	1.64	67.8
3	1.75	61.0
4	1.68	58.0
5	1.75	86.7
6	1.75	93.5
7	1.53	73.3
8	1.75	74.3
9	1.75	81.3
10	2.20	114.5
11	1.83	71.8
13	1.75	103.3
14	2.10	111.3
15	2.03	92.7
16	1.75	68.2
17	1.75	91.3
18	1.64	79.0
19	1.89	68.7
20	2.39	105.5
21	1.68	71.5
22	2.10	81.2

From Table 4.4, the data of 12^{nd} sample was omitted from discussion, this was because when graph which was Figure 4.3 was plotted, the data was deviated from normal distribution line and considered as an outlier data. Discussion was made without data of 12^{th} sample. Figure 4.3 shows the relationship between mean texture depth (MTD) and British Pendulum Number (BPN) of 21 asphalt cement pavement samples.

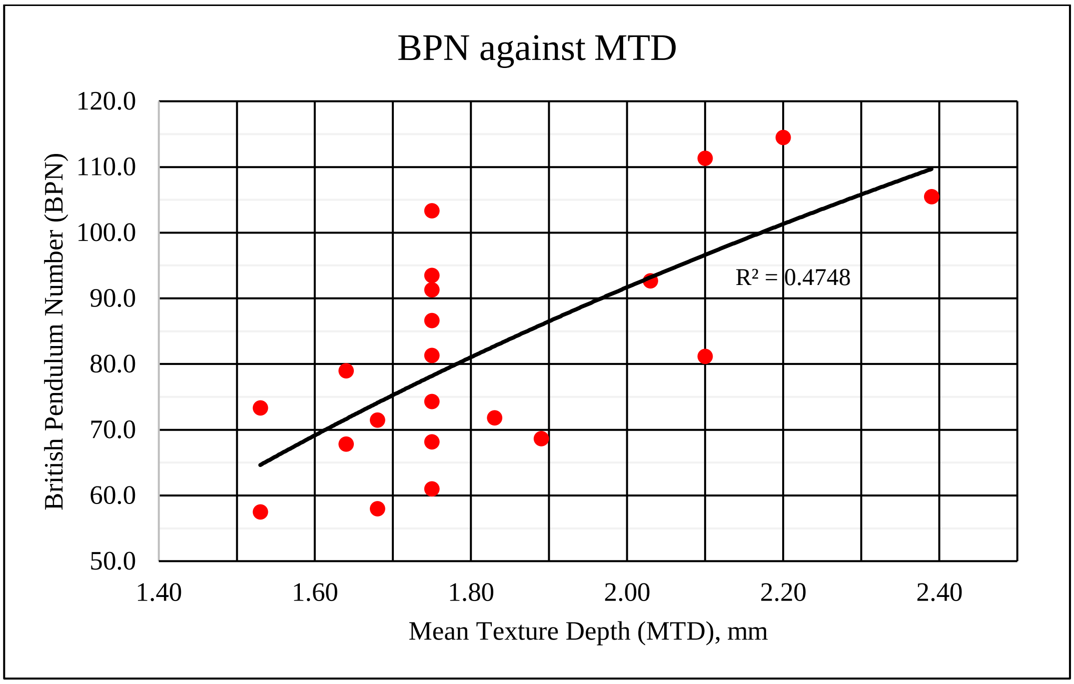

Figure 4.3: Relationship between mean texture depth (MTD) and British Pendulum Number (BPN) of 21 asphalt concrete pavement samples

From Figure 4.3, the relationship between mean texture depth (MTD) and British Pendulum Number (BPN) could be obtained. The trends was showing that the increasing of mean texture depth (MTD), the increasing of British Pendulum Number (BPN) until a maximum point. The data showing that the optimum skid resistance performance recorded at BPN value of 114.5 at 2.20 mm of mean texture depth. After 2.20 mm of mean texture depth, the skid resistance performance was decreasing.

From Figure 4.3, the correlation could be made between mean texture depth (MTD) and British Pendulum Number (BPN). The trend line showed a positively relationship. The gradient of the correlation graph showed directly proportional relationship between MTD and BPN. Hence, the increasing of MTD, the increasing of BPN until a maximum point. The value of correlation coefficient showing a value of 0.4748. According the classification of the strength of correlation coefficients, it belonged to medium positively correlated ($0 < R^2 < 0.5$).

Based on the value of correlation coefficient, it could be concluded that skid resistance of pavement which was British Pendulum Number (BPN) was dependent on macrotexture parameter which was mean texture depth (MTD). Researchers found that both macrotexure and microtexture did affect the skid resistance performance, it was cannot solely to conclude that macrotexture be the solely factor to affect skid resistance of pavement (Lu *et al.* 2006). Meanwhile, British pendulum tester was testing at a low swing speed, it was unavailable to represents the skid resistance of pavement at a high speeds (Lu *et al.* 2006).

Another researchers investigated that macrotexture characteristics on Portland cement concrete (PCC) pavement and asphalt concrete (AC) pavement affect texture friction (Ahammed & Tighe 2008). Ahammed & Tighe (2008) concluded that the optimum BPN value of 83 was recorded with MTD value of 1.84 mm for PCC pavement. The greatest MTD recorded as 1.86 and 2.17 mm showed that lower skid resistance performance when compared to the similar or lower MTD. Researchers interpreted that the BPN value achieved a maximum point and will drop due to the exposed aggregate on pavement was loss of sand microtexture characteristics (Ahammed & Tighe 2008). In addition, there was good correlation between BPN value and MTD for PCC pavement. R^2 value of 0.906 and 0.958 were obtained for the study.

4.5 SUMMARY

This chapter presented the outcome of the thesis to achieve objectives. Mean texture depth (MTD) for each samples had been recorded in section 4.2. In this section, 3 diameters of circular sand had been identified, average diameter was calculated and used for calculation to get MTD. The MTD recorded varied from 1.53 mm to 2.39 mm. British pendulum number (BPN) for each samples had been recorded in section 4.3. In this section, 6 values of BPN were considered and used for calculation of average of BPN value. The BPN collected varied from 57.7 to 114.5. Correlation of MTD and BPN had been analysed in section 4.4. 2.20 mm of MTD showing the optimum skid resistance performance of pavement samples. The value of correlation coefficient was obtained which was 0.4748.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the outcome of this research, 22 asphalt concrete pavement samples were prepared with wearing course, AC14. Brushing of binder and spreading of chip seal were done on top surface of each pavement samples. Two tests were carried out to measure the macrotexture characteristics of chip seal. The first test was volumetric patch test and the macrotexture characteristics which was mean texture depth (MTD) was determined. From volumetric patch test, the mean texture depth (MTD) recorded as 1.53 mm to 2.39 mm. Another test was carried out which was British pendulum test and British Pendulum Number (BPN) value of chip seal was collected. BPN recorded in this research varied from 57.7 to 114.5. There was correlation between mean texture depth (MTD) and British Pendulum Number (BPN). BPN increased with the increasing of MTD until a maximum point and BPN value was decreasing due to loss of sand microtexture characteristics. The result shown that 2.20 mm of MTD showing the optimum skid resistance performance of pavement samples. There was one set of datum was omitted due to categorized as outlier. Total of 21 set of data were analysed. The value of correlation coefficient was obtained which was 0.4748. This was showing that was a medium positively correlated between MTD and BPN.

5.2 RECOMMENDATION

Based on this study, there is some elements can be improved in order to have comprehensive study on the research which are:-

1. The asphalt concrete pavement samples can be done more than 30 samples to get the wide range result of mean texture depth (MTD).

2. The scope of research can be include the consideration of both microtexture and macrotexture characteristics to improve skid resistance performances.

3. The scope of research can be include the pavement with wet condition, by using outflow test to trace the hydroplaning potential of pavement texture characteristics.

4. The research can be include the drainage ability of pavement and to determine the relationship between drainage ability and macrotexture characteristics resulting to increase skid resistance performance.

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APPENDIX A

RAW DATA OF BRITISH PENDULUM NUMBER (BPN)

Sample	BPN 1	BPN 2	BPN 3	BPN 4	BPN 5	BPN 6	BPN 7	BPN 8	BPN 9
1	55	56	56	50	72	62	62	59	57
2	55	53	66	56	72	81	55	66	66
3	53	52	64	59	66	52	65	57	55
4	55	52	66	54	37	59	54	77	60
5	76	85	90	80	92	86	73	74	87
6	90	100	101	90	100	77	79	80	124
7	66	95	77	113	69	80	74	74	87
8	75	65	75	61	71	85	78	71	76
9	70	77	85	77	87	95	88	85	77
10	93	130	112	119	147	97	100	116	110
11	100	71	70	70	95	60	65	78	77
12	140	146	99	122	137	136	108	101	100
13	91	118	96	110	105	100	71	88	80
14	120	93	101	140	114	106	115	112	95
15	96	101	91	81	84	85	90	93	118
16	94	64	56	53	77	66	63	63	76
17	85	93	106	99	87	94	115	70	90
18	73	75	87	89	92	86	59	74	79
19	74	48	60	62	59	52	68	76	72
20	85	112	94	104	104	100	108	105	96
21	80	72	59	75	70	53	74	70	68
22	65	64	89	76	80	76	84	92	82