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Skid Resistance Measuring Techniques Using Portable Testing Tools for Road Application

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Abstract

Pavement skid resistance is another highway element that has a direct impact on driving safety. Adequate pavement skid resistance is a key requirement for safe road operations. Poor safety pavement happened due to less friction between vehicle tyres and pavement that cause problems for driver to control vehicle in proper movement and direction. The conventional measurement and prediction of the skid resistance apparatus is a highly challenging due to rapid development that. Thus, this article elaborated on state-of-art of the recent progress of testing apparatuses and evaluation techniques concerning for skid resistance was illustrated in detail in term of mechanism, measurement, methods and application. Measurement techniques of skid resistance in situ such as. The current advances for skid resistance of asphalt pavement from recognized research works are summarized. This manuscript recommends a few key research directions such as the gap between current and conventional portable apparatus of skid resistance should be linked to identify more precise approximation of frictional pavement properties in the phase of testing. Besides that, the article established standard testing procedures for measurement of microtexture and macrotexture of asphalt pavement.

1. Introduction

Asphalt pavement should provide road users with safety. In recent years, poor safety performance has contributed to road accidents. Over time, the performance of road pavement deteriorates. It is influenced by traffic, particularly heavy vehicles that carry more weight than cars and motorcycles. It is also affected by the vehicle, driver, pavement, and environmental factors such as weather. Annually, around 1.17 million death cases have been recorded due to traffic accidents. From this data, about 70% was reported from developed countries as 65% of death belongs to pedestrians. To be exact, around 23-34 million accidents have been documented due to road calamities [1]. Several factors leading to accident and causalities are such as pavement condition, high acceleration, driving behaviour, driving awareness, environmental effects, manoeuvring and vehicle factors. Additionally, vehicle damage and discomfort riding due to high levels of pavement roughness and distress are those major factor lead toward road accident [2]. In general, pavement conditions can be classified into three classes such as mild, moderate and severe pavement conditions. For instance, condition of poor pavement are polished surface, depression, potholes and unevenness [3].

According to McGovern [4], nearly 20% of traffic incidents occurred during rainy days as the wet asphalt pavement causes the potential of tyre skidding. In general, the wet pavement condition along with the design of road geometry and factor of driver would incur the accident possibility during rainy weather [5]. The term of "skid resistance" can be referred as the evaluation of texture properties which indicates the friction between pavement surface and vehicle tyres. The skidding happened as a force was generated to prevent the tyres from rotating slides along the road surface as shown in Figure 1. The pavement surface texture contribute to significant contact with tyres to allow greater force to prevent skidding. The texture can be divided into micro and macro-textures [6]. The force on the road surface would be exerted by the vehicle tyres when driver manoeuvre in the stationary area where tyres produce friction, the road surface inhibits the turning force[7]. In general, there are various ways to influence the contact of tyres with the road surface such as tangent, curve land location, grade and super-elevation. Aforementioned issue has led to the necessity in determining the pavement skid resistance properties to ensure the safety is well-maintained in long-term use.

Fig 1. Acting forces on a rotating tire [8].

Several studies have been reviewed in various aspects including the influence of skid resistance and tyre-pavement friction [8]–[10]. However, less literatures discussed in-depth to consider the impact of some of the aforementioned parameters and measurement of skid resistance efforts and tools. On the top of that, the subject matter of pavement skid resistance is a fast developing research work. Hence, practitioners and researchers need to keep abreast with the latest developments in the field. Principally, three types of testing techniques used to evaluate the skid resistance properties including sideway force coefficient (SFC), longitudinal friction coefficient (LFC) and stationary movement (sliders) [11]. Thus, this research narrowed on slow-moving measurement (sliders) such as British Pendulum Tester (BPT) and Dynamic Friction Tester (DFT) due to the portability of the machines to evaluate the condition of skid resistance operating the road pavement. These type of devices implements rubber sliders that attached either to a rotating head or the foot of a pendulum arm, which slow down interaction with the pavement surface, which easy to operate and less time consuming.

In this manuscript, it focuses on the recent progress and comparison of two types of tester mechanisms which are BPT and DFT. Both BPT and DFT machines were compared since both testers implements low-speed pavement measuring method. This review provide comprehensive views of both testers which exhibits distinct outcomes of skid resistance parameters which could promote better data evaluation and analysis for pavement engineering. At the end of the study, this research aims to establish a correlation between traditional and recent skid measurement tool since both of techniques have similar operation (slider with stationary measurement).

2. Skidding Phenomenon

Skid resistance influence by the contact of the tyre pavement with resulting friction force on the pavement surface [12]. Some factors that affect the friction of pavement-tyres are displayed in Table 1.

Table 1 Factors pavement friction.

Factors	Attributes
Tire Attributes	• Rubber configuration • Sliding temperature for velocity • Tread condition and design • Pressure • Foot print
Environmental Condition	• Weather • Temperature • Water
Surface Properties of Pavement	• Macrotexture • Megatexture • Microtexture • Temperature • Substantial
Operational of Vehicles	• Bracking • Acceleration • Manuevering • Cornering

The friction allows the driver to operate the vehicle safely during acceleration, braking, cornering and maneuvering. The measurement of pavement friction is not simple task, since measuring the frictional forces are subject to a variety of variables that are difficult to regulate. These factor parameters are measured from the pavement include the surface, temperature or substantial and from the tire aspect such as rubber configuration, sliding temperature for velocity, etc. Nonetheless, all the factors that contribute remain constant throughout the friction measurement excluding the road surface. Main principals of friction in skid resistance are adhesion and hysteresis[13]. The interaction between hysteresis and adhesion would affect the braking distance of the vehicle, mostly on wet pavement. Figure 2 displays the relationship between adhesion and hysteresis grip in pavement analysis [14].

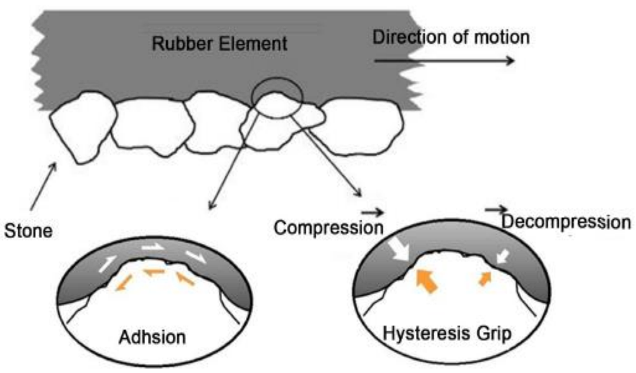

Fig 2. Skid resistance analysis: adhesion and hysteresis [15].

Hysteresis happens as the energy loss due to the tyre structure deformation around the depressions and protuberances on the pavement surface [15]. The hysteresis mechanism is independent to the speed whereas the adhesive mechanism is speed dependent. The hysteresis friction is associated with involvement of some scale textures [16]. Friction influences the maximum value during high-speed slide movement while slow speed slide move adhesion when exceed the maximum value shown by the hyteresis phenomenon [17]. All of those are frictional approaches to surface hysteresis and rubber wear [18].

Friction satisfactory can be determined by the average slope and texture shape from linear regression analysis [19]. The pavement surface and tyre has real contact area which can be correlated with adhesion and shear strength [8]. Adhesion occurs due to molecular interactions at high local pressure areas which causes unevenness in pavement surface. The adhesion friction acts as dominant when the slip exceed a critical point. The adhesion occurs on the surface pavement during wet pavement when the driving speed combines two of resistant force.

3. Relationship skid resistance and accident

Adequate skid resistance of pavement surface provides safety and smooth rides for road users. High skid resistance of pavement reduced the maintenance cost as well as improve road durability for long-term serviced. Low quality of pavement surface would cause skidding problem especially during wet condition that may incur the accident and severity. In general, dry road surface vehicle can easily manoeuvre due to adequate friction [20]. In accordance to Schulze et al. [21], the rate of accidents of wet pavement is reversely proportional to friction coefficient as shown in Figure 3. Other studies demonstrate that more that 3 percent uphill or downhill due to slope have high risk of accident in the wet pavement area [22]. Possibility lead to decrease the pavement skid is due tocrainfall, deteriorated surface road or poor road design geometry. This indicates that one of the road accident factor occur because the reduced coefficient of skid resistance on the pavement that causes the vehicle to sliding on the road.

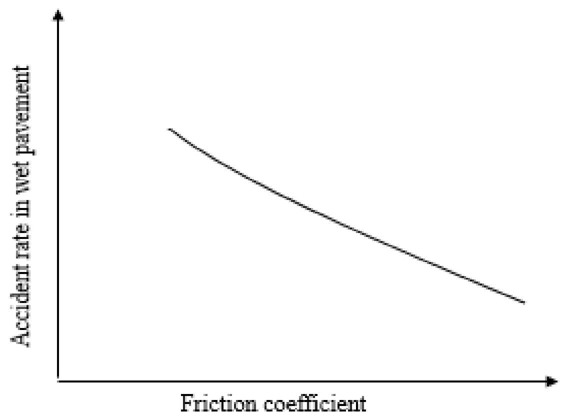

Fig 3. The relationship between accident rate in pavement during wet weather and friction coefficient [21].

Most of researchers are narrowed their works on the increasing the service life of road pavement, however, lack of study for the selection, mixture design and the use of aggregate in order to improve the pavement performance. The friction coefficient between tyre and road surface can be defined as the quotient of the tangential force at the tire-pavement contact interface and the longitudinal force on the wheel. The friction coefficient (μ) is given as:

$$\mu = \frac{F}{Fw} \quad (1)$$

Where; μ is coefficient of friction, F is friction force between contact rubber tyre with road surface and Fw is applied weight to the tyre. Based on the fundamental calculation, skid resistance of pavement can be determined by using laboratory and in-situ equipment and tools. Table 2 shows a list of measuring devices of pavement to evaluate the skid resistance.

Table 2. Summary of measuring device of skid resistance.

Test Method	Measurement Principle	Operation and measurement	Ref
British Pendulum Test	Pendulum test	• The BPT machine analyses the reading measurement using British Pendulum Number (BPN) • Evaluation is based on after low speed sliding contact with height of pendulum, with the pavement surface	[23], [24]
Dynamic Friction Tester	Rotating friction	• DFT numbers or friction coefficients • Displays the graph of the friction coefficient for different rotational speeds. • Evaluated based on International Friction Index (IFI), and peak friction	[25]
Side-force	Sideways force coefficient (SFC)	• Measure average of the side force perpendicular to the plane of rotation. • Used on roundabout, T-sections, curves, or straight sections. • Measure accurately wet-road skidding resistance. • The sideway force and vertical load developed by frictional resistance to skid of the test wheel that measured using transducers	
SCRIM	Sideways force coefficient (SFC)	• Measure accurately wet-road skidding resistance. • The vertical load and the sideway force generated by the frictional resistance to skidding of the test wheel are measured using transducers	
Locked wheel	Longitudinal friction coefficient (LFC)	• Measuring the resistive drag force and the wheel load applied to the pavement. • Non-time consuming performance.	
Fixed slip	Longitudinal friction coefficient (LFC)	• Measuring the resistive drag force and the wheel load applied to the pavement. • It presents continuous measurement and high resolution data collected.	

During rainy days, water acts as lubricant and it traps between rubber tyres and pavement surface by forming a layer that reduce the contact area. The significant reduction of tyre-pavement contact areas would decrease the grip effect of tyre as friction coefficient reduce [26]. The pavement surface would have inadequate friction and friction decreased as the water layer covers the surface. Installation drainage can cause water film blockage that be a factor to hydroplaning. Hydroplaning occurs due to formation of water film between tyres and pavement surface which restricting the driver loss control the vehicle as failed to respond actions like accelerating, braking and steering [27]. In addition, uncontrolled driving due to slipperiness road surface causes increasing rate of accident rate of the road user [28].

4. Pavement Surface Texture

Pavement wearing surface is main topic in order to develop good mixture design with good friction, low levels of noise and low levels of roughness [29]. In general, the wet pavement would cause serious problems in conjunction to low skid resistance, vehicle speed and heavy traffic. Insufficient maintenance for pavement causes the probability for pavement skidding increase the rate accidents over the years. The parameters easily can be managed by pavement design and speed limit regulation such as macrotexture, megatexture and microtexture pavement properties and slip speed. The texture classification was divided based on the wavelength of its components as depicts in Table 3 [30].

Table 2. Classification pavement wavelength [30].

Texture Classification	Macrotexture	Megatexture	Microtexture
Relative Wavelengths	0.5 mm < λ < 50 mm	50 mm < λ < 500 mm	3 λ < 0.5 mm

The microtexture and macrotexture depend on aggregate characteristics which determine the sizing and gradation for pavement. The wet pavement surface of microtexture usually provide adhesion between tyre-pavement surface [31]. The term of "microtexture" is referred as surface property in particular to angularity, shape of aggregate and surface texture which improve drainage of water. The improved microtexture of pavement would reduce the deformation of tyres as the kinetic energy were decrease. This would give smooth rides experience for vehicle driver [32]. The microtexture and macrotexture is essential to create friction force to assist the driver to manoeuvre the vehicle in steady and comfort journey [33]. In this case, the adhesion forces would establish greater coefficient of friction which permit interlocking effect between tyre and road surface as contact from rubber tyre over the road surface. This phenomenon could affected the molecular bonds being sheared and subsequently grip the tyre safely in wet pavement.

Fwa [34] stated the speed of vehicle affects skid resistance of pavement surfaces for microtexture and macrotexture. The macrotexture can be described that the increasing of vehicle speed can control the slope of skid resistance reduction while the microtexture discusses the magnitude of skid resistance. In addition, the occurrence on road surface for skid resistance would decrease through reduce the friction-speed gradient that will preserve water drainage system that influence macrotexture during high speeding. The microtexture relation established on arrangement spacing between microasperities and the average height [15]. According to Ong et al. [35] study that the good selection material important cause hydroplaning can be reduced and microtexture can be enhanced. Their findings display for hydroplaning usually 20 percent would be achieved at higher velocity because coarse aggregate and high microtexture in the pavement. The pavement is made up of aggregate, binder and asphalt mix properties as well as post-placement treatment. The macrotexture of pavement is affected by the maximum aggregate size, mix gradation and mix air content, fine and coarse aggregate types and mix binder content and viscosity. Meanwhile the microtexture is mostly affected by the coarse aggregate.

5. Asphalt pavement analysis: Aggregate and mixture properties

In the selection of pavement material, appropriate amount of aggregate, asphalt, binder, additive and filler are required to be determined and those good mix design would result in good performance of skid resistance of pavement. Another main property needs to be considered to design pavement with high skid resistance is the aggregate polishing properties. Aggregate polishing properties provide the pavement surface sufficient skid resistance. Among those properties, the characterization of microtexture of aggregates is essential to ensure sufficient friction efficiency to increase the contact area between tyre and pavement surface [36]. The property data would aid in measuring the influence of asphalt content in pavement after the mixture placement. Thus, the characterization and analyses of the pavement's properties has substantial contribution in the improvement of skid resistance of road which aids in reducing cost of the surface treatment, rehabilitation and maintenance. The assessment selection aggregate and asphalt properties can the developing satisfactory mixture and good system that correlated with skid resistance [37].

5.1 Aggregates properties

Aggregate properties with its test methods affect the performance of asphalt pavement [38]. Aggregates are divided depending on their size either fine, intermediary or coarse. The physical, mechanical, and chemical properties of aggregates is main role in the flexible and rigid pavements performance. The aggregate has different rate and ability either polish or smooth to resist polishing action traffic [39].

5.2 Soundness

Another factor in the selection of pavement material during construction is soundness ability of aggregate to resist the forces of weathering. The primary exposure that concerned during soundness test is the freezing and thawing conditions [40]. Strong aggregates which resistant to weathering are less likely to vitiate in the field and cause premature hot mixed asphalt (HMA) pavement distress and could be failed. The requirement of soundness test for aggregates (coarse and fine) is depended on sodium or magnesium sulphate contents.

5.3 Abrasion

Abrasion of aggregate usually is used to characterise the aggregate component in term of the resistant toward crushing, degradation and disintegration [41]. Abrasion test implements to measure the hardness of aggregates which commonly recommended in highway construction application. Moreover, main parameter to determine the quality of the aggregates.

5.4 Polish Stone

The resistance toward polishing effect of aggregate happened after grinding and shearing due to repeat traffic loading on pavement structure. The polishing rate is influenced by three main factors, such as traffic frequency, roughness of material on roadway and grain hardness. In order to achieve good polishing resistance, the cementing matrix has to be durable. Thus, to calculate the parameter of polishing resistance, polished stone value (PSV) has to be attained in a specific standard test. In general, the frictional properties of the aggregate needs to be able to withstand the polishing action of the passing traffic [15].

5.5 Shape, texture and angularity

Another factor needs to measure in order to identify the skid resistance of pavement was shape, texture and angularity of aggregate. These characteristics are significant for micro and macro texture. The shape factor represents variations in the compositions of a particle. Meanwhile, angularity is influenced by the crushing techniques for variations at the corners. Surface texture can be detailing that aggregate mineralogy for the surface irregularity or asperities at a very small scale [42]. For instance, flat and elongated particles tend to be horizontally oriented, which resulting in lower macrotexture depth. For sharp and angular coarse aggregate particles, they interlock and give greater macrotexture depth. Two of the most commonly used methods for aggregate shape, texture and angularity are uncompact void content of coarse aggregate and fractured-faced particles test. Angularity of coarse aggregates would contribute to tyre-pavement friction in term of asphalt concrete while the aggregates seal coats provide point contacts as it protrudes above the water level with the tyre surface. However, different mineral composition of aggregate with the same angularity could be differed in rate of wear-polish [43].

5.6 Frictional properties by asphalt mixtures

Pavement is made up of coarse and fine aggregates and petroleum-based asphalt binder as it is graded by aggregate quality, aggregate gradation, mix design method, and asphalt content [44]. In term of asphalt mixture performance, aggregate plays essential component since their shape, texture, chemical properties, and gradation would permit varies results in the volumetric properties of asphalt mixture. As in aforementioned statement above, aggregate gradation and surface mixture finish quality effect on the surface macrotexture of pavement. Several international standard tests are usually conducted to identify properties and interaction of asphalt mixture such as Hveem, Marshall and Superpave methods [45]. The effect on the frictional properties of asphalt mixtures of the various types and grades of asphalt binder is beyond the scope of this study.

6. Skid resistance measurement methods

Various devices and tests were used by many pavement engineering researchers to evaluate skid resistance of road surface. Different measurement methods implement different applications and parameters. The methods can be classified in two component that is field measurement and portable and laboratory testers. Figure 4 explain detailed for two components with the devices used.

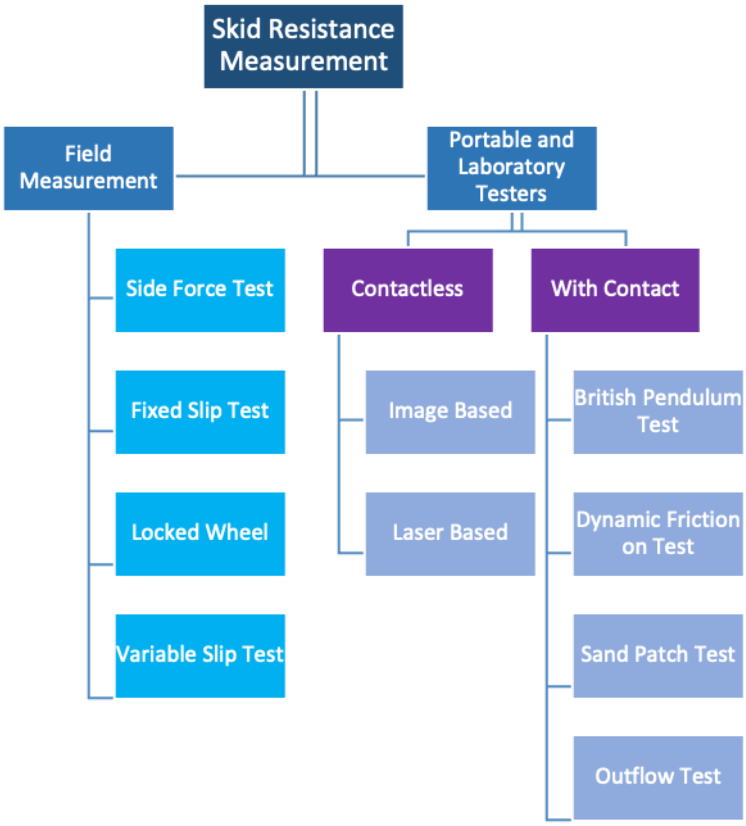

Fig 4. Classification skid resistance measurement.

The measurement devices analysis indicated different function with some advantages. For the field measurement, side force test presents constant measurement throughout a test pavement section and has advantage for direction motion that can be used in straight sections, curves and steep grades [15]. This method is sensitive to changes in pavement microtexture and road irregularities like cracks and potholes which can destroy tires quickly but unaffected with pavement macrotexture. Locked wheel measures the steady-state friction force on a locked test wheel as it is dragged under constant load and at constant speed that typically at 64 km/hour over a wet pavement surface. In the locked wheel method, the skid speed is equal to the vehicle speed that can be interpret the test wheel is locked and unable to rotate. This method measured under sudden braking condition for a vehicle without anti-lock brakes. In this test, water is sprayed on the pavement surface in front of the test tire when the tire reaches test speed in order to simulate wet conditions. Friction of the pavement surface is determined from the resulting force or torque and is reported as skid number (SN). Fixed slip device uses the test wheel rotates with a constant slip for example the wheel is lightly braked to provide a difference in velocity between the test wheel and the speed of the tester. The slip ratio is usually between 10 and 20 percent. This is usually accomplished by incorporating a gear reduction of the test wheel drive shaft from the drive shaft of the host vehicle, or through hydraulic retardation of the test wheel. One of fixed slip device commonly used in Europe is the GripTester as shown in Figure 5. Friction measured with this device is related to braking with antilock brakes.

Fig 5. GripTester [46].

Electro-optic or lased-based measuring skid resistance instrument is useful for high-speed friction measurements as shown in Figure 6. It is capable to determine friction of wide range of texture parameters. This tool is applicable to estimate the macrotexture of pavement and it is limited to assess microtexture surface only at 0.03–0.5 mm wavelengths. However, the measurement of microtexture of pavement only under high accuracy wavelength range not shorter than equipment's spot size of 0.05 mm. Several research works [27], [47] have deployed three dimensional (3D) modelling and areal texture parameters of surface texture with different wavelength to establish holistic view of skid resistance of pavement by using 3D laser scanning device. Laser scanners such as the triangulation types, allow the calculation of new texture indicators by produce 3D models. These indicators which includes surfaces and volumes, permit better stability and complete texture characterization of pavement surface. However, these laser scanner tools are quite expensive in price.

Fig 6. Laser method [8].

Another testing devices that apply in measuring friction properties of road pavement surfaces is British pendulum tester (BPT) as depicted in Figure 7. The machine are conducted based on international standard, ASTM E303 (Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester). BPT machine is specifically to be used in order to characterize the microtexture of pavement. This testing machine is generally cheap and simple tool as compared to other portable skid resistance measuring devices [24]. The BPT device is easy to control and handle to collect data on macrotexture frictional characteristics. It can be functioned in both field and laboratory with low speed data measurement. In general, the BPT machine is suitable for various climate and condition to measure the texture and friction. The measurement collect the data for spot measurement and can be conducted lateral and longitudinal for pavement tyre friction.

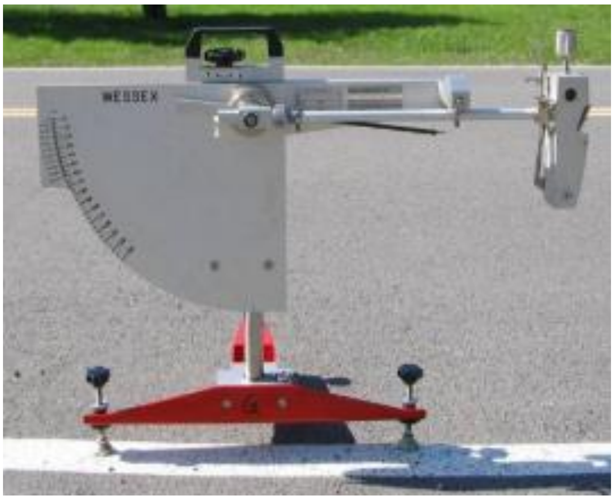

Fig 7. British Pendulum Tester [25].

Dynamic Friction Tester (DFT) as shown in Figure 8 evaluates microtexture surface of pavement by exerting friction force between the rubber pads that attach to disc rotating surface. The test allows the contact between rubber pad and pavement surface in various speed, as disc is moved horizontally to allow measurement of skid resistance [48]. The speed used in constant load is around 20 to 80 km/hour. This testing tool can be used in both laboratory and actual field. It can accommodate maximum values for friction coefficient and better repetition. Eventhough this device has many advantages, it cannot measure tyre-pavement friction property as in BPT due to it can record data in fixed spot measurement with controlled traffic.

Fig 8. Dynamic Friction Tester [25].

The assessment of texture properties skid resistance for pavement surface performed with the conventional tests like the British pendulum and sand patch tests [49]. The "Sand Patch" test measures the average depth of the pavement surface macrotexture. The calculated texture depth of the surface on which the sand patch test is performed, is called by the mean texture depth (MTD) [50]. Sand patch method requires lane closure for evaluate small area for only macrotexture. The surface of the material should be level with the highest points of the aggregate. The average macrotexture depth is calculated by dividing the volume of material by the average diameter of the circle.

7. Conclusions

Several essential parameters which impact the measurement of skid resistance of asphalt pavement have been identified and reviewed. A short overview of several general approaches to assess major aspects of tyre-pavement friction has also been provided. This review manuscript established a brief and general view of current references on the subject matter which not discussed in other literatures including the testing methods of skid resistance. In this manuscript, it focuses on portable and laboratory test for pavement surface including those essential parameters that influence the skid resistance of road surface. The frictional performance of asphalt pavements largely depends on the type and quality of coarse aggregates in the asphalt mixture besides the pavement surface texture, polishing effect, soundness and abrasion. There is still a need to develop experimentally-validated models for predicting asphalt pavement skid resistance, especially for warm and wet surfaces to provide smooth travel and reduced contact noise between tyres and road.

Several categories of methods and devices are generally can be used to measure skid resistance of surface texture in road pavement such as field measurement and portable devices. These two types of devices have their own limitation and restriction to assess the road pavement's skid resistance properties. To conclude, measurement methods should have ability to all types of condition and road network. New development methods that can achieve result in minimum time with faster speed and not involve the lane closure and traffic control. The evaluation to measure skid resistance and frictional characteristics using measurement methods can efficiently achieve the good skid resistance performance of pavements that can improve the safety of road user.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

Mazlan Rafidah and Sitti Asmah Hassan did the project administrations. Mazlan Rafidah,Mohd Khairul Afzan Mohd Lazi, FM Jakarni and Siti Nur Naqibah Kamarudin wrote the main manuscript text. Muhammad Irfan Shahrin, Muhammad Farhan Zolkepli, and Muhammad Naqiuddin Mohd Warid reviewed the manuscript

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