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# **Pavement Surface Characteristics as Influenced by Material Properties**

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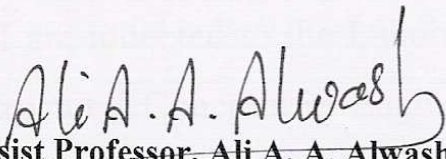
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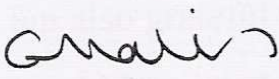
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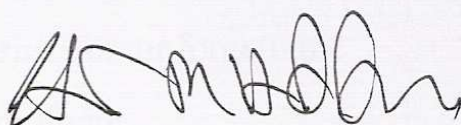
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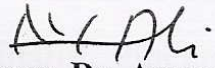
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# Abstract

Skid resistance is the most important property of pavement surface that must be taken into consideration in the design of roads and should be adequate to resist skidding of vehicles to ensure the safety of human life and economic.

The aim of the study is to investigate the effects of several variables: aggregate maximum size (1",  $\frac{3}{4}$ ", and  $\frac{1}{2}$ "), mix ratio (1:1.5:3, 1:2:4, and 1:3:6), finishing conditions (rough and smooth), water to cement ratio (0.65, 0.55, and 0.45) and surface conditions (wet and dry) on the skid resistance of rigid pavement and the effects of aggregate maximum size (1",  $\frac{3}{4}$ ", and  $\frac{1}{2}$ "), asphalt content (4.1, 4.7, 5.3, and 6), gradation limit (fine gradation, intermediate gradation, and coarse gradation), and surface conditions (wet and dry) of flexible pavement, and then to control the variables in the design and construction phases of highway in order to obtain the best possible of pavement performance.

The British Pendulum Tester (ASTM E303) and the Volumetric Method (Sand Patch) (ASTM E965) are the main tests for the skid resistance in addition to fundamental tests such as Marshall, Compressive Strength, Tensile Strength, and Modulus of Elasticity, in order to examine the properties of the mixture for concrete and asphalt surface. Although, from a safety point; it is negative to increase skid resistance but this increasing leads to increasing of tire wearing and levels of noise.

Three cases of flexible and rigid pavements are selected to investigate the effects of several variables (speed, traffic volume, density and texture depth) on the noise level, using Statistical Passby (SPB) and Controlled Passby (CPB). Sound level pressure has been increased by 104% for increased in traffic volume from 1400 to 1868 veh/hr, 119% and 117% for increased in vehicle speed on rigid pavement and flexible pavement respectively from 20 km/hr to 50 km/hr and 105% for increased in texture depth of pavement.

The skid resistance (F60) has been increased by 103% for increased in aggregate maximum size from  $\frac{1}{2}$ " to  $\frac{3}{4}$ ", 112% for replace the mix ratio from 1:1.5:3 to 1:2:4 and 115% for replace the smooth to rough as concrete finishing conditions and decreases the water/cement ratio from 0.55 to 0.45 has increased the skid resistance (F60) by 122%; while for flexible pavement the skid resistance (F60) has been increased by 118% for increased in aggregate maximum size from  $\frac{1}{2}$ " to  $\frac{3}{4}$ ", asphalt content of paving mixtures from 4.7% to 5.3% causes an decreased skid resistance by 93% and the skid resistance increases using coarse gradation.

From the experimental work, it was found that; the variable that more control on the skid resistance of flexible pavement is maximum aggregate size. The variables that more control on the skid resistance of rigid pavement is mix ratio, water/cement ratio and finishing conditions.

A regression equation has been obtained to predict the Friction Number (F60) as related to aggregate maximum size, mix ratio, finishing conditions, and water to cement ratio of rigid pavement and the effects of aggregate maximum size, asphalt content, and gradation of flexible pavement.

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## SYMBOLS

| Symbols | Means                                                                                  |
|---------|----------------------------------------------------------------------------------------|
| AC      | Asphalt Concrete.                                                                      |
| BPN     | British Pendulum Number.                                                               |
| BPT     | portable British Pendulum Tester.                                                      |
| CPB     | Controlled Pass-By.                                                                    |
| CTM     | The Circular Texture Meter.                                                            |
| dB      | Decibel.                                                                               |
| dB(A)   | A-weighted decibel.                                                                    |
| F(60)   | Friction number of the International Friction Index (IFI) (Normalized friction value). |
| F       | Friction force between vehicle tire and pavement surface.                              |
| FHWA    | Federal Highway Administration                                                         |
| FN      | Friction number at the measured speed.                                                 |
| FR60    | Adjusted friction value to 60 km/hr.                                                   |
| FRS     | Friction measured by the equipment at the slip speed (BPN).                            |
| MPD     | Mean profile depth.                                                                    |
| MTD     | The mean texture depth.                                                                |
| OFM     | The Outflow Meter.                                                                     |
| PCC     | Portland cement concrete.                                                              |
| SN      | Skid number.                                                                           |
| Sp      | The speed constant.                                                                    |
| SPB     | Statistical Pass-By.                                                                   |
| SPBI    | Statistical Pass-By Index.                                                             |
| SPL     | sound pressure level (dB).                                                             |

|           |                                                      |
|-----------|------------------------------------------------------|
| SPM       | The Sand Patch Method.                               |
| TX        | Macrotexture measurement in millimeters.             |
| W         | Vertical load applied to the tire, lb.               |
| WFT       | The water film thickness.                            |
| $\lambda$ | The wavelength (m).                                  |
| $\mu$     | Coefficient of friction.                             |
| L10(1 h)  | The noise level exceeded for 10% of a 1-hour period. |
| L50(1 h)  | The noise level exceeded for 50% of a 1-hour period. |
| L90(1 h)  | The noise level exceeded for 90% of a 1-hour period. |

# CHAPTER ONE

## **Introduction**

# Chapter 1

## Introduction

### 1.1 Background:

Pavement–tire friction (or simply pavement friction) is one of the primary factors determining highway safety and, in particular, the probability of wet skidding crashes. Highway agencies have recognized this fact since the 1920's. The probability of wet skidding crashes is reduced when friction between a vehicle tire and pavement is high (**Moyer, 1959**).

Skid-related crashes are determined by many factors, wet pavement friction being only one of them. Other factors, such as road geometry, traffic characteristics, vehicle speed, and weather conditions, must be considered together with friction data when evaluating the safety of a particular section of roadway.

Pavement surfaces should provide adequate friction and maintain a good level of ride quality to ensure satisfaction of the driving public. In particular, it is important for the safety of the driving public that roads provide adequate friction at the tire-pavement interface. The combination of good friction, low levels of roughness, and low levels of noise are important in pavement wearing surface design. Approximately 15% of fatal and injury causing accidents occur during wet weather, some of which are due to friction deficiencies at the pavement surface (**Smith, 1976**).

The surface texture of a pavement-wearing surface is one of the primary contributors to tire-pavement friction. Both macrotexture and microtexture affect the friction characteristics of pavement surfaces. Increasing the texture of in-service or new pavement surfaces will increase the skid resistance levels of the pavement. However, increases in texture will sometimes increase the level of discomfort for vehicle occupants (**Ivey 1981**).

To maintain adequate levels of friction on pavement surfaces, many state transportation departments perform routine skid resistance testing. The type of equipment used for testing varies, depending on the preferences of each transportation department. Unfortunately, friction measurements are not consistent among different types of equipment and cannot be directly compared unless the same type of equipment is used (**Wambold, 1995**).

The Permanent International Association of Road Congresses devised a method for the comparison of pavement surface frictional properties in 1995. The International Friction Index uses texture properties in conjunction with friction testing to normalize measurements made by different types of equipment. The International Friction Index, which is not yet widely used, may allow for comparisons of pavement surface friction throughout the world, leading to advances in skid resistant pavement design (**Wambold, 1995**).

Unfortunately, increasing pavement friction also has negative aspects. They include increased fuel consumption, tire wear, and noise inside the vehicle.

Noise is defined as a sound that is loud, unpleasant, or disturbing. Whether at home, at work, or at play, people will be affected when exposed

to excessive noise. Over-exposure to excessive noise will result in negative impacts to the community. This can range from physical discomfort (e.g. disturbs sleep or rest) to substantial impacts to health (e.g. loss of hearing) **(Pearsall, 2002)**.

Traffic noise is a serious problem. Engine, and aerodynamic and pavement/tire noise contribute to traffic noise. The FHWA (Federal Highway Administration) Noise Abatement Criteria states that noise abatement must be considered for residential areas when the traffic noise levels approach or exceed 70 dB (A) for L10 **(Douglas, et al, 2004)**.

Field sound level measurements, Statistical Passby (SPB) and Controlled Passby (CPB) Methods are performed to determine the amount of sound attenuation level of each pavement **(Douglas, et al, 2004)**.

## **1.2 Research Objective:**

The objectives of this work is to evaluate the skid resistance properties of both flexible and rigid pavement under some variables of material (asphalt content, gradation limit, aggregate maximum size, mix ratio, finishing conditions, and water to cement ratio) and environmental factors (surface conditions) and also determine the sound levels ability of various types of pavements that are commonly used.

## **1.3 Thesis Layout:**

To achieve the objective of this research, the work should include the following:

- 1- Chapter two is focused on the review of literature related to skid resistance and noise level.

- 2- The details of the experimental work required for this study with the information on material properties and testing equipment are given in chapter three.
- 3- The research results and discussion are presented in chapter four.
- 4- Finally, the extracted conclusions from previous chapters and recommendations for further studies are presented in chapter five.

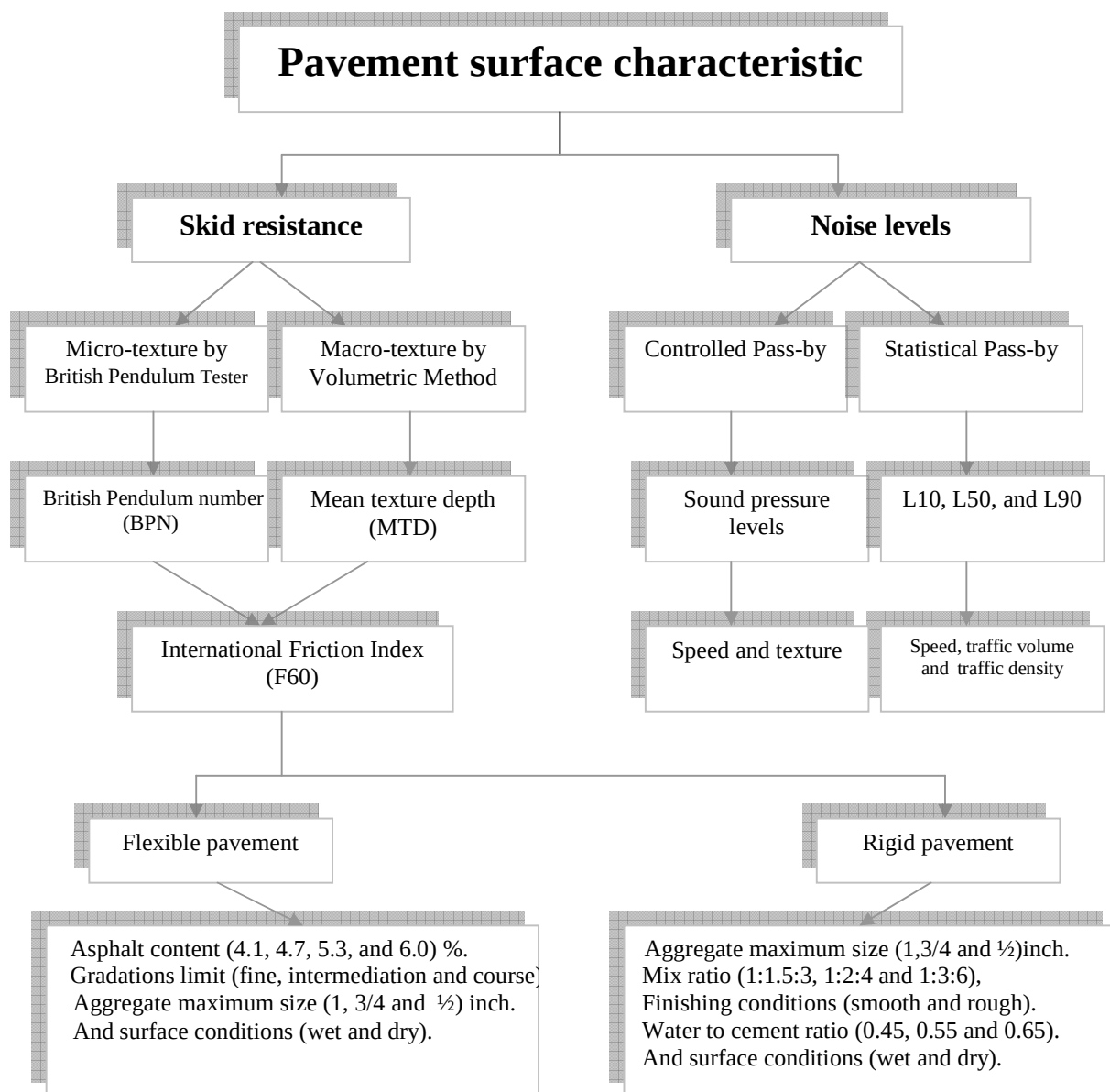


**Figure (1.1): flow chart of test program.**

# CHAPTER TWO

## **Literature**

## **Review**

# Chapter 2

## Literature Review

### 2.1 Introduction

Pavement engineering is the selection of design, materials, and construction practices to ensure satisfactory performance over the projected life of the pavement. Pavement users are sensitive to the functional performance of pavements –noise and skid resistance – rather than structural performance. Pavements, as a general rule, develop distresses gradually over time under traffic loading and environmental effects. An exception is when poor material choices or construction practices cause defects before or shortly after the pavement is put into service (**Taylor & Francis, 2008**).

Pavement friction is the opposing force developed at the tire-pavement contact area. In other words, pavement friction is the force that resists the tire sliding on pavement surfaces. Pavement friction is an essential component of traffic safety as it is critical in maintaining vehicle control and reducing the stopping distance in emergency braking situations.

The accidents are a result of numerous reasons including driver error, vehicle malfunction, and friction deficiencies at the tire-pavement interface. Accidents resulting from a friction deficiency of the pavement surface are more likely to occur with the accumulation of precipitation

such as rain (**Lu 1996**). A film of moisture on the pavement surface, resulting from precipitation, may prevent vehicle tires from making adequate contact with the surface of the road.

The measurement of pavement skid resistance is of critical importance to highway agencies worldwide. The key point of interest is the frictional resistance generated between the vehicle tires and the pavement surface that allow a moving vehicle to be brought to a stop. The greater the frictional resistance mobilized, the quicker the vehicle can be slowed or stopped (**Taylor & Francis, 2006**).

Increased traffic volumes and speeds have increased the need for an improved skid-resistant surface. There have been many improvements in tire technology over the past 30 years, including advances in tire compounds, tread patterns, and tread depths. All of the improvements are aimed at ensuring maximum contact between the tire and the pavement surface at all speeds, with generation of high frictional resistance under braking conditions(**Taylor & Francis, 2006**).

From a road agency standpoint, the aim must be to supply and maintain pavement surfaces that provide maximum frictional resistance to braking tires(**Taylor & Francis, 2006**).

Unfortunately, increasing pavement friction also has negative aspects. They include increased fuel consumption, tire wear, and noise inside the vehicle. However, the negative aspects of increasing pavement friction are outweighed by the potential decrease in the number of accidents occurring from inadequate pavement friction (**Ivey, 1981**).

Since then research into the skidding problem has been two-pronged. First, it has been necessary to establish from accident statistics limits of slipperiness which can be tolerated on various types of road, bearing in mind, on the one hand, the cost of accidents, and, on the other, the

increased cost of providing high-quality nonskid road surfaces. Second, the attributes necessary in the road surface both to obtain and to retain adequate resistance to skidding have needed close study (**Croney, et al, 1997**) .

Noise from highway traffic is an environmental problem in both metropolitan and rural areas (**The Boston Globe. 2004 ; Krupa 2003 ; Michigan Department of Transportation.2004**). The most significant impact of traffic noise is the annoyance it causes to humans and the associated negative effects this annoyance has on the quality of life. However in addition to annoyance, traffic noise may also impact health (**World Health Organization, 1999**), create difficulty with speech communication, suppress real estate values, and cause the stagnation of economic expansion due to public resistance to expanded highway capacity.

Highway traffic noise is generated by four sub- sources of highway vehicles: engine noise, aerodynamic noise, and tire/pavement interaction noise.

## **2.2 Importance of Pavement Friction**

### **2.2.1 Highway Safety**

Between 1990 and 2003, an average of 6.4 million highway crashes (all vehicle types) occurred annually on the nation's highways, resulting in 3 million injuries, 42,000 fatalities, and countless amounts of pain and suffering. This rate of fatality equates to 115 fatalities per day, or 1 death every 12 minutes (**Noyce et al., 2005; National Highway Traffic Safety Administration [NHTSA], 2004**). In 2000, the cost of highway crashes was estimated at \$230.6 billion (**Noyce et al., 2005; NHTSA, 2004**).

Figure 2.1 present summaries of the total number of crashes in the U.S. between 1990 and 2003. According to the National Transportation Safety Board (NTSB) and the FHWA, approximately 13.5 percent of fatal crashes and 25 percent of all crashes occur when roads are wet (**Kuemmel et al., 2000**).

One or more factors contribute to highway crashes. These factors fall under three main categories: driver-related, vehicle-related, and highway condition-related (**Noyce et al., 2005**). Of these three categories, only highway condition can be controlled by highway agencies through design, construction, maintenance, and management practices and policies. Many highway-related conditions influence safety (e.g., geometric design, intersection and roadside design, pavement surface conditions [friction, texture, distress, noise level]).

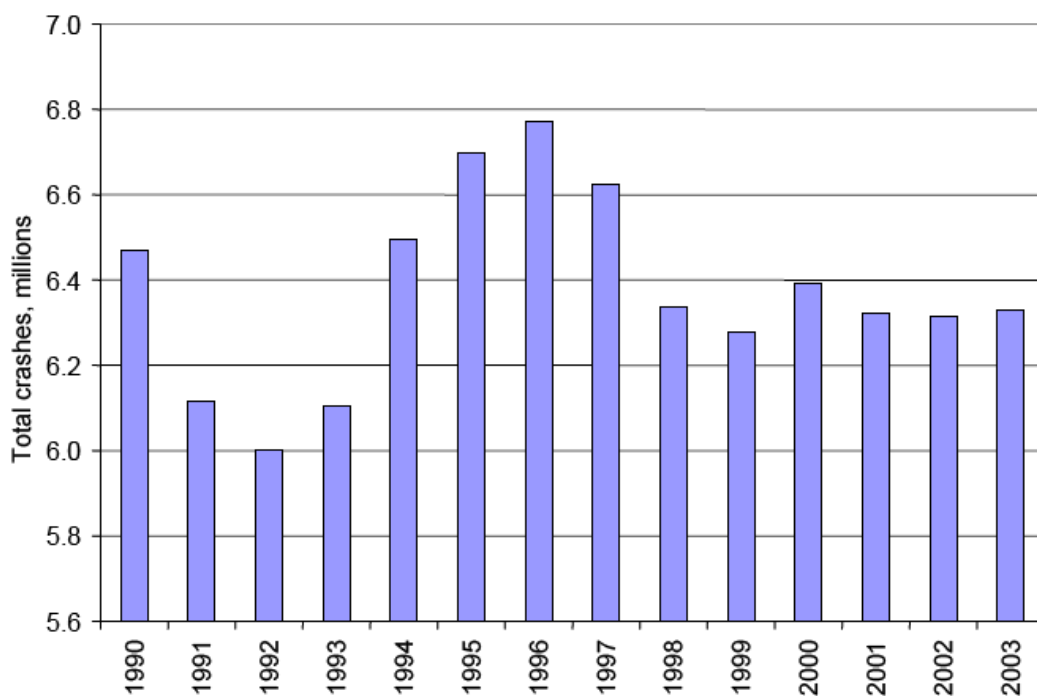


**Figure 2.1: Total crashes (from all vehicles types) on U.S. highways from 1990 to 2003 (NHTSA, 2004).**

### 2.2.2 Crash Reduction

The friction developed between vehicle tires and a pavement surface is a critical factor in controlling and reducing crashes (**Henry, 2000; Ivey et al., 1992**).

The horrendous social and economic costs associated with road accidents must be minimized by road agencies and maintenance of adequate skid resistance throughout the agency's network is a key requirement in this regard. There is also the reality for road agencies of the growth in litigation in relation to accidents worldwide. The ability to demonstrate standards, policies, and monitoring of road networks to ensure adequate skid resistance is becoming essential in this context as well as in the broader public interest (**Taylor & Francis 2006**).

A 2000 Missouri court case demonstrated the need for acceptable friction levels for pavement maintenance; two vehicles collided because of poor skid resistance. In this particular crash, one person died and another was seriously injured. The court ruled that it is the responsibility of the state Department of Transportation (DOT) to improve skid resistance and/or warn the motorist when highway is slippery to prevent crashes of this nature(**Missouri Court, 2003**).

Although research has confirmed a basic relationship between pavement friction and wet crash rates, it has not established an exact relationship nor identified any specific threshold friction values below which wet crash rates increase substantially (**Henry, 2000; Larson, 1999**). This is because friction demand (i.e., the level of friction needed to prevent a vehicle from slipping) varies with location and time due to changing site conditions, traffic characteristics, and driver/vehicle characteristics. While a particular friction value may satisfy demand at one location and at one moment in time, the same value may not satisfy the demand at another

location or at a different moment in time. Thus, control of friction at the network level must be based on periodic assessments of friction (and crashes) at the pavement segment/unit level **(Hall, 2006)**.

### **2.2.3 Skid Resistance and Drivers Behavior**

Maintaining acceptable skid resistance levels on the roadways is very important for traffic safety. Yet it is difficult to correlate the effects of pavement friction values on crash risk. Usually, drivers adjust their driving behavior (namely speed) based on the appearance of the road environment and the current weather conditions. Certainly, it can be argued that some drivers change their behavior as a result of changes in pavement friction **(FHWA, U.S. Department of Transportation, 1998)**.

It is important to note that not only different weather conditions lead to different pavement friction values - the same pavement can yield variable friction levels under the identical weather condition. Clearly this can be misleading to drivers by violating their expectancy **(Minsk 1998)**.

A Policy on Geometric Design of Highways and Streets (Green Book), published by AASHTO, states that the stopping distance provided in a roadway “should be sufficiently long to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path” **(AASHTO,2001)**. To accomplish this, the level of skid resistance in the roadway should be enough to accommodate the braking and steering maneuvers needed **(Noyce et al , 2007)**.

Table 2.1 provides AASHTO’s design stopping distance values for different speeds at deceleration rates based on friction criteria described in the AASHTO’s Guidelines for Skid Resistant Pavement Design **(AASHTO, 1976)**.

Table 2.1: Stopping Sight Distance (AASHTO, 2001)

| METRIC                                                                                                                                               |                         |                           |                         |        | U.S. CUSTOMARY |                         |                           |                         |        |
|------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|---------------------------|-------------------------|--------|----------------|-------------------------|---------------------------|-------------------------|--------|
| Design Speed                                                                                                                                         | Brake Reaction Distance | Braking Distance on Level | Stopping Sight Distance |        | Design Speed   | Brake Reaction Distance | Braking Distance on Level | Stopping Sight Distance |        |
|                                                                                                                                                      |                         |                           | Calc.                   | Design |                |                         |                           | Calc.                   | Design |
| (km/h)                                                                                                                                               | (m)                     | (m)                       | (m)                     | (m)    | (mph)          | (ft)                    | (ft)                      | (ft)                    | (ft)   |
| 20                                                                                                                                                   | 13.9                    | 4.6                       | 18.5                    | 20     | 15             | 55.1                    | 21.6                      | 76.7                    | 80     |
| 30                                                                                                                                                   | 20.9                    | 10.3                      | 31.2                    | 35     | 20             | 73.5                    | 38.4                      | 111.9                   | 115    |
| 40                                                                                                                                                   | 27.8                    | 18.4                      | 46.2                    | 50     | 25             | 91.9                    | 60.0                      | 151.9                   | 155    |
| 50                                                                                                                                                   | 34.8                    | 28.7                      | 63.5                    | 65     | 30             | 110.3                   | 86.4                      | 196.7                   | 200    |
| 60                                                                                                                                                   | 41.7                    | 41.3                      | 83.0                    | 85     | 35             | 128.6                   | 117.6                     | 246.2                   | 250    |
| 70                                                                                                                                                   | 48.7                    | 56.2                      | 104.9                   | 105    | 40             | 147.0                   | 153.6                     | 300.6                   | 305    |
| 80                                                                                                                                                   | 55.6                    | 73.4                      | 129.0                   | 130    | 45             | 165.4                   | 194.4                     | 359.8                   | 360    |
| 90                                                                                                                                                   | 62.6                    | 92.9                      | 155.5                   | 160    | 50             | 183.8                   | 240.0                     | 423.8                   | 425    |
| 100                                                                                                                                                  | 69.5                    | 114.7                     | 184.2                   | 185    | 55             | 202.1                   | 290.3                     | 492.4                   | 495    |
| 110                                                                                                                                                  | 76.5                    | 138.8                     | 215.3                   | 220    | 60             | 220.5                   | 345.5                     | 566.0                   | 570    |
| 120                                                                                                                                                  | 83.4                    | 165.2                     | 248.6                   | 250    | 65             | 238.9                   | 405.5                     | 644.4                   | 645    |
| 130                                                                                                                                                  | 90.4                    | 193.8                     | 284.2                   | 285    | 70             | 257.3                   | 470.3                     | 727.6                   | 730    |
|                                                                                                                                                      |                         |                           |                         |        | 75             | 275.6                   | 539.9                     | 815.5                   | 820    |
|                                                                                                                                                      |                         |                           |                         |        | 80             | 294.0                   | 614.3                     | 908.3                   | 910    |
| <b>Note: Brake reaction distance predicted on a time of 2.5s; deceleration rate of 3.4 m/s<sup>2</sup> [11.2 ft/s<sup>2</sup>] used to determine</b> |                         |                           |                         |        |                |                         |                           |                         |        |

Values portrayed in Table 2.1 are a function of the brake reaction time, the design speed and the deceleration rate measured when adequate friction is present (**AASHTO,2001**). Equation 2.1 shows the model used in the Green Book to calculate braking distance: (**Öberg G, 1981**)

$$d = 1.075 \frac{V^2}{a} \quad \text{-----2.1}$$

Where

d: braking distance, ft

V: design speed, mph

a: deceleration rate, ft/s<sup>2</sup>

Equation 2.1 assumes a deceleration rate of 11.2 ft/s<sup>2</sup>. Using this deceleration rate to calculate stopping distance indirectly infers that the pavement has a specific pavement friction value. A minimum friction value is obtained from Equation 2.2.

$$a = fg \quad \text{-----2.2}$$

where,

a: acceleration, ft/s

f: friction coefficient

g: acceleration of gravity, 32.2 ft/s<sup>2</sup>

Solving for f, the yielded friction number (FN) value is 34.8 which can be approximated as 35. If Friction Number becomes less than 35, the AASHTO principles in Equation 2.1 may not apply since the needed stopping distance will be greater than what AASHTO recommends.

## 2.3 Pavement Friction Principles

### 2.3.1 Definition of Pavement Friction.

Pavement friction is the force that resists the relative motion between a vehicle tire and a pavement surface. This resistive force (illustrated in Figure 2.2) is generated when the tire rolls or slides over the pavement surface. A measure of the resistive force is the non dimensional coefficient of friction,  $\mu$ , which as expressed in equation 2.3, is the ratio of the tangential friction force ( $F$ ) between the tire tread rubber and the horizontal traveled surface to the perpendicular force or vertical load ( $F_w$ ) (Hall, 2006).

$$\mu = \frac{F}{F_w} \quad \text{-----2.3}$$

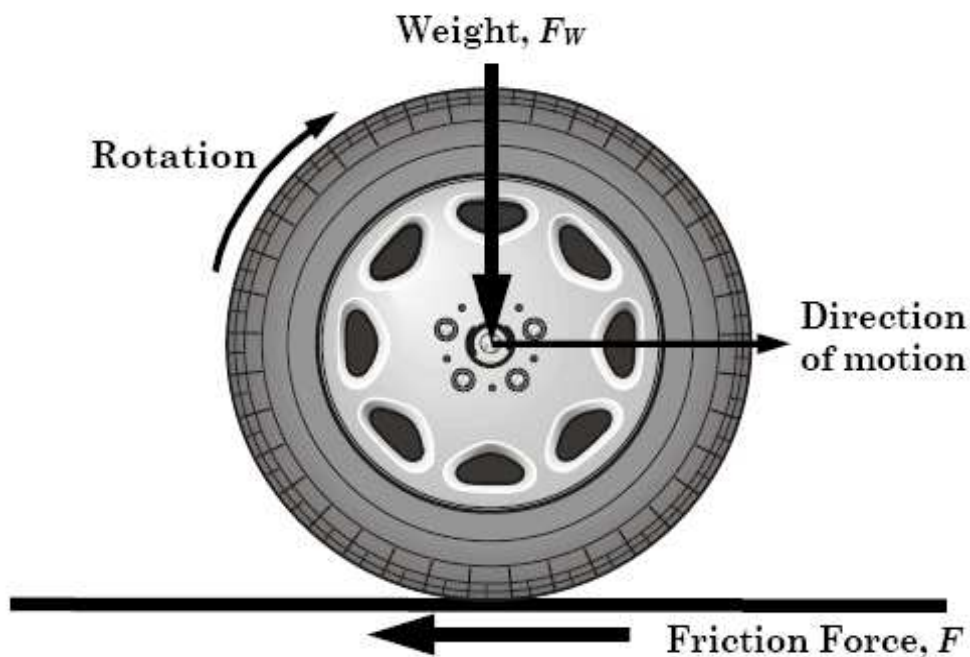


Figure (2.2): Simplified diagram of forces acting on a rotating wheel (Hall, 2006).

### 2.3.2 Mechanisms of Pavement Friction.

Pavement friction is the result of a complex interplay between two principal frictional force components—adhesion and hysteresis (Figure 2.3). Although there are other components of pavement friction (e.g., tire rubber shear), they are insignificant when compared to the adhesion and hysteresis force components. Thus, friction can be viewed as the sum of the adhesion and hysteresis frictional forces (**Hall, 2006**):

$$F = F_A + F_H \quad \text{-----2.4}$$

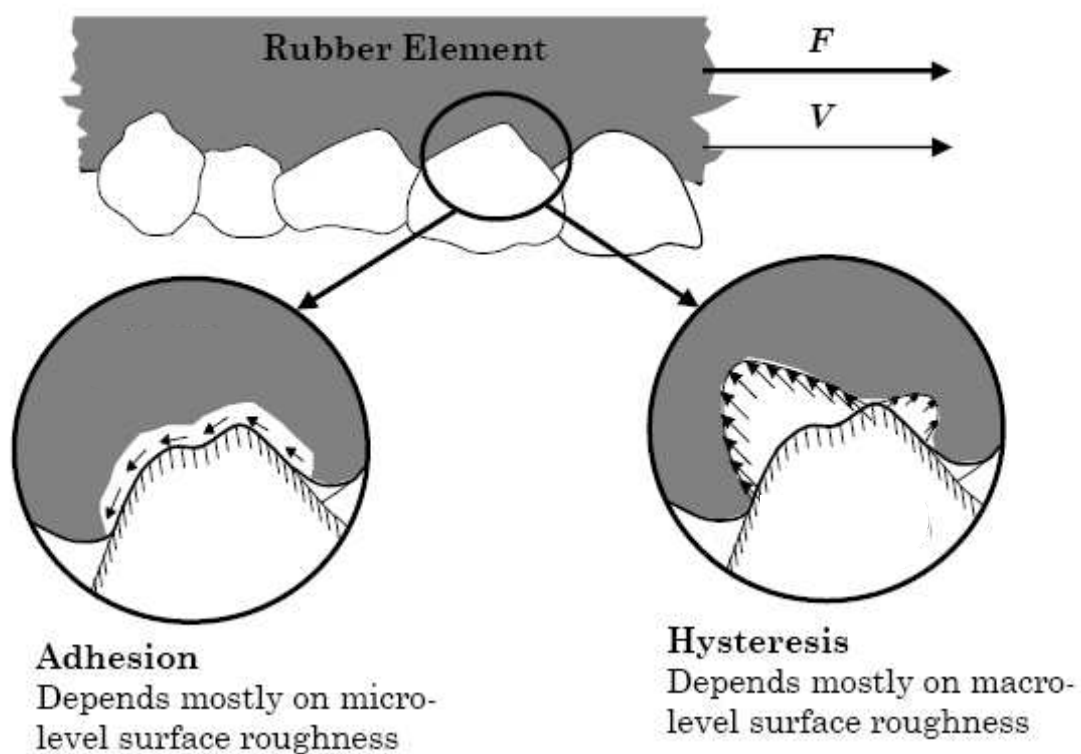


**Figure (2.3): Key mechanisms of pavement–tire friction (Hall, 2006).**

Adhesion is the friction that results from the small-scale bonding/interlocking of the vehicle tire rubber and the pavement surface as they come into contact with each other. It is a function of the interface shear strength and contact area. The hysteresis component of frictional forces results from the energy loss due to bulk deformation of the vehicle tire. The deformation is commonly referred to as enveloping of the tire around the texture. When a tire compresses against the pavement surface, the stress distribution causes the deformation energy to be stored within the rubber. As the tire relaxes, part of the stored energy is recovered, while the other part is lost in the form of heat (hysteresis), which is irreversible. That loss leaves a net frictional force to help stop the forward motion.

Surface texture influences both mechanisms. The adhesion force is proportional to the real area of adhesion between the tire and surface asperities. The hysteresis force is generated within the deflecting and visco-elastic tire tread material, and is a function of speed. Generally, adhesion is related to micro-texture, whereas hysteresis is mainly related to macro-texture. For wet pavements, adhesion drops off with increased speed, while hysteresis increases with speed. Also, because tire rubber is a visco-elastic material, each component is affected by temperature and sliding speed (Hall, 2006).

## **2.4 Friction Measurement Methods**

### **2.4.1 Methods and Equipment**

AASHTO and ASTM have developed a set of surface characteristic standards and measurement practice standards for both friction and texture. These standards ensure comparability of the measurements for specific purposes; they are grouped according to measurements performed at

highway speeds (i.e., high-speed devices) and measurements requiring lane closure (i.e., low-speed/walking and stationary devices).

In general, the measurement devices requiring lane closure are simpler and relatively inexpensive, whereas the highway-speed devices are more expensive and require more training to maintain and operate. With the recent development of technology in data acquisition, sensor technology, and data processing power of computers, the once true superiority of data quality for the stationary and low-speed devices is diminishing. The resolution and accuracy of the acquired data for the measurement devices that are low speed or stationary can be still superseding that of the high-speed devices, but with smaller and smaller margins (**Hall, 2006**).

The locked-wheel friction tester (**AASHTO T 242**) is the predominant high-speed device used on U.S. roads. This device requires a tow vehicle and a locked-wheel skid trailer, equipped with either a standard ribbed tire(**AASHTO M 261**) or a standard smooth tire(**AASHTO M 286**). Friction measurements are obtained by locking the test tire (ribbed or smooth) on a wetted pavement surface while traveling at a specified speed (40 mi/hr [64 km/hr] is the standard speed given in **AASHTO T 242**). Portable friction measurement equipment requiring lane closures include the BPT(**AASHTO T 278**) and the Dynamic Friction Tester (DFT) (**ASTM E 1911**).

High-speed texture measuring equipment includes laser profilers, such as the FHWA Road Surface Analyzer. These non-contact devices use a combination of a horizontal distance measuring device, a very high-speed (64 kHz or higher) laser triangulation sensor, and a portable computer to collect and store pavement surface elevations (vertical resolution usually 0.002 in [0.5 mm] or better) at intervals of 0.01 in (0.25 mm) or less. From

these elevations, the system calculates the mean profile depth (MPD), which is an overall measure of macro-texture.

Texture measuring equipment requiring lane closures include the Sand Patch Method (SPM) (ASTM E 965), the Outflow Meter (OFM) (ASTM E 2380), and the Circular Texture Meter (CTM) (ASTM E 2157).

### 2.4.2 Friction indices

Friction indices have been in use for a long time. In 1965, ASTM started the use of the Skid Number (SN) (ASTM E 274) as an alternative to the coefficient of friction. In later years, AASHTO adopted the ASTM E 274 as AASHTO T 242 test method and changed the terminology from Skid Number to Friction Number (FN). In the early 1990s, Permanent International Association of Road Congresses (PIARC) developed the International Friction Index (IFI), based on the PIARC international harmonization study. A refined IFI model was developed shortly thereafter as part of a Ph.D. thesis (Rado, 1994).

The use of friction indices has allowed for harmonization of the different sensitivities of the various friction measurement principles to micro-texture and macro-texture. Provided below are brief discussions of these primary friction indices.

#### 2.4.2.1 Friction Number

The Friction Number (FN) (or Skid Number [SN]) represents the average coefficient of friction measured across a test interval. It is computed as follows:

$$FN = 100 \times \mu = 100 \times (F/W) \quad \text{-----2.5}$$

where:

FN = Friction number at the measured speed.

$\mu$  = Coefficient of friction.

F = Tractive horizontal force applied to the tire, lb.

W = Vertical load applied to the tire, lb.

The reporting values range from 0 to 100, with 0 representing no friction and 100 representing complete friction.

FN values are generally designated by the speed at which the test is conducted and by the type of tire used in the test. For example, FN40R = 36 indicates a friction value of 36, as measured at a test speed of 40 mi/hr (64 km/hr) and with a ribbed (R) tire. Similarly, FN50S = 29 indicates a friction value of 29, as measured at a test speed of 50 mi/hr (81 km/hr) and with a smooth (S) tire.

#### 2.4.2.2 International Friction Index

The International Friction Index (IFI) was developed during the PIARC International Experiment to Compare and Harmonize Texture and Skid Resistance Measurements to overcome the differences among measurement devices (**Wambold, 1995**). The IFI uses measurements of skid resistance and texture to evaluate the pavement surface characteristics and is being adopted worldwide for skid resistance comparison. To calculate the IFI it is necessary to have at least one friction measurement and one macrotexture measurement (**ASTM E 1960**). The IFI is reported in two parameters: the normalized friction value at 60 kilometers per hour (F60) and a speed constant related to the pavement friction value (Sp). A transformation equation has also been established to allow for calculation of the IFI at speeds other than 60 kilometers per hour based on the 60-kilometer per hour values (**Davis, 2001**).

The speed constant, Sp, is calculated using Equation 2.6 if an appropriate texture measurement is available.

$$S_p = a + b \cdot TX \quad \text{-----2.6}$$

The constants  $a$  and  $b$  are dependent on the measurement method used to obtain the macrotexture parameter  $TX$  in millimeters. The applicable values for the texture measurements used in that research are shown in Table 2.2.

**Table 2.2: Constants for Speed Constant Equation (Davis, 2001).**

| TX (mm)                                                                                       | a     | b     |
|-----------------------------------------------------------------------------------------------|-------|-------|
| MPD (ASTM E 1845 Standard Practice for Calculating Pavement Macrotexture Depth)               | 14.2  | 89.7  |
| MTD (ASTM E 965 Test Method for Measuring Pavement Macrotexture Using a Volumetric Technique) | -11.6 | 113.6 |

For calculation of the IFI, the speed at which the friction parameters are measured needs to be adjusted to the required 60 kilometer per hour. Using the speed constant and the measured friction values, the adjusted value of friction can be calculated as follows:

$$FR_{60} = FRS * e^{\frac{S-60}{S_p}} \quad \text{-----2.7}$$

Where:

$FR_{60}$  = Adjusted friction value to 60 km/hr,

$FRS$  = Friction measured by the equipment at the slip speed (BPN),

$S$  = Slip speed in kilometers per hour, and

Sp = Speed constant.

The adjusted friction value and the texture measurement are then used to calculate the value for F60.

$$F60 = A + B*FR60 + C*TX \quad \text{-----2.8}$$

Where:

F60 = Normalized friction value,

A, B, and C = Calibration constants,

FR60 = Value calculated using Equation 2.7, and

TX = Macrottexture measurement in millimeters .

The parameters used in Equation 2.8 are dependent upon the measurement equipment used. **ASTM E1960** lists values for many different types of equipment. The values for the parameters are listed in Table (2.3). It can be observed that the macrottexture term appears only when the ribbed tire is used (**Davis, 2001**).

**Table 2.3: The values for the parameters for Calculating F60 (Davis, 2001).**

| Tire Type Used | Slip Speed (km/hr) | A      | B       | C     |
|----------------|--------------------|--------|---------|-------|
| Blank          | 65                 | 0.045  | 0.00925 | 0.000 |
|                | 60                 | 0.0436 | 0.0095  |       |
| Ribbed         | 65                 | -0.023 | 0.00607 | 0.098 |

## 2.5 Factors Affecting Available Pavement Friction

The factors that influence pavement friction forces can be grouped into four categories—pavement surface characteristics, vehicle operational parameters, tire properties, and environmental factors. Table 2.4 lists the various factors comprising each category. Because each factor in this table plays a role in defining pavement friction, friction must be viewed as a process instead of an inherent property of the pavement. It is only when all these factors are fully specified that friction takes on a definite value.

The more critical factors are shown in bold in Table 2.4. and are briefly discussed below. Among these factors, the ones considered to be within a highway agency's control are micro and macro-texture, pavement material properties, and slip speed (**Wallman and Astrom, 2001**).

**Table 2.4: Factors affecting available pavement friction (Wallman and Astrom, 2001).**

| PAVEMENT SURFACE CHARACTERISTICS                                                                                                                                                                          | VEHICLE OPERATING PARAMETERS                                                                                                                                                                                                                                                      | TIRE PROPERTIES                                                                                                                                                                                                                    | ENVIRONMENT                                                                                                                                                                                                                                                                                                                                                            |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>· <b>Micro-texture</b></li> <li>· <b>Macro-texture</b></li> <li>· Mega-texture/ unevenness</li> <li>· <b>Material properties</b></li> <li>· Temperature</li> </ul> | <ul style="list-style-type: none"> <li>· <b>Slip speed</b> <ul style="list-style-type: none"> <li>- vehicle speed</li> <li>- braking action</li> </ul> </li> <li>· Driving maneuver <ul style="list-style-type: none"> <li>- turning</li> <li>- overtaking</li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>· Foot Print</li> <li>· <b>Tread design and condition</b></li> <li>· Rubber composition and hardness</li> <li>· <b>Inflation pressure</b></li> <li>· Load</li> <li>· Temperature</li> </ul> | <ul style="list-style-type: none"> <li>· Climate <ul style="list-style-type: none"> <li>- Wind</li> <li>- <b>Temperature</b></li> <li>- <b>Water (rainfall, condensation)</b></li> <li>- Snow and Ice</li> </ul> </li> <li>· Contaminants <ul style="list-style-type: none"> <li>- Anti-skid material (salt, sand)</li> <li>- Dirt, mud, debris</li> </ul> </li> </ul> |

Note: Critical factors are shown in bold.

### 2.5.1 Pavement Surface Texture

Pavement surface texture is made up of the deviations of the pavement surface from a true planar surface. These deviations occur at three distinct levels of scale, each defined by the wavelength ( $\lambda$ ) and peak-

to-peak amplitude (A) of its components. The three levels of texture, as established by the Permanent International Association of Road Congresses (PIARC) (1987), are as follows:

- Micro-texture ( $\lambda < 0.02$  inch [0.5 mm],  $A = 0.4 \times 10^{-5}$  to 0.02 inch [0.001 to 0.5 mm]). Surface roughness quality at the sub-visible/microscopic level. It is a function of the surface properties of the aggregate particles within the asphalt or concrete paving material.

- Macro-texture ( $\lambda = 0.02$  to 2 inch [0.5 to 50 mm],  $A = 0.005$  to 0.8 inch [0.1 to 20 mm]). Surface roughness quality defined by the mixture properties (shape, size, and gradation of aggregate) of an asphalt paving material and the method of finishing/texturing (dragging, tining, grooving; depth, width, spacing and orientation of channels/grooves) used on a concrete paving material.

- Mega-texture ( $\lambda = 2$  to 20 inch [50 to 500 mm],  $A = 0.005$  to 2 inch [0.1 to 50 mm]). This type of texture is the texture which has wavelengths in the same order of size as the pavement–tire interface. It is largely defined by the distress and defects on the pavement surface.

Wavelengths longer than the upper limit (20 inch [500 mm]) of mega-texture are defined as roughness or unevenness (**Henry, 2000**).

Figure 2.4 illustrates the three texture ranges, as well as a fourth level—roughness/unevenness—representing wavelengths longer than the upper limit (20 inch [500 mm]) of mega-texture (**Sandburg, 1998**).

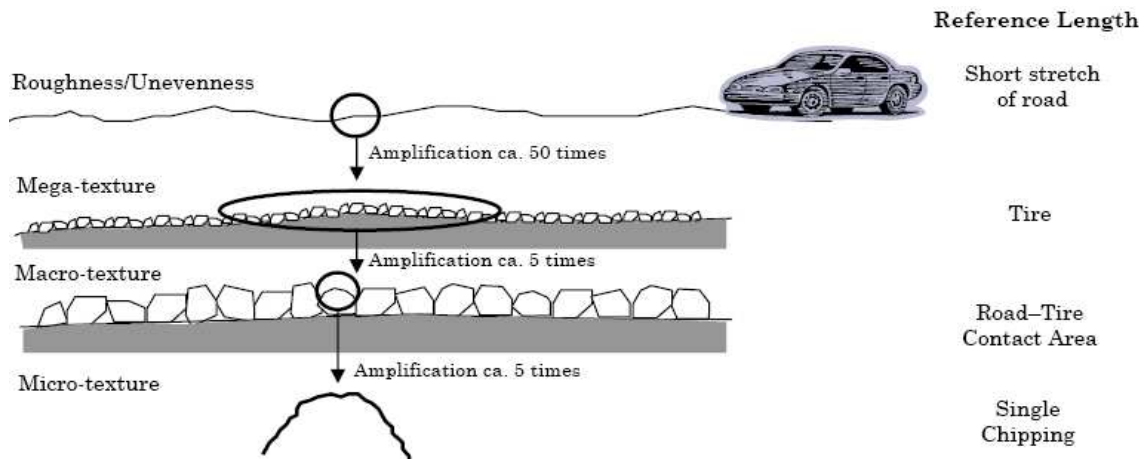


**Figure 2.4: Simplified illustration of the various texture ranges that exist for a given pavement surface (Sandburg, 1998).**

### 2.5.1.1 Microtexture and Macrottexture

In the provision of pavement surfaces with adequate skid resistance, there are two primary parameters that need to be provided and measured: microtexture and macrottexture.

Microtexture is primarily a property of the individual pieces of aggregate making up the road surface. The microtexture of the aggregate controls the contact between the tire rubber and the pavement surface. The microtexture characteristics of an aggregate are governed by the crystalline nature of the aggregate itself.

In the provision of sufficient frictional resistance to bring a moving vehicle to a stop, microtexture provides the primary source of frictional resistance at low speeds (less than 50 km/h) due to the direct interaction between the tire rubber and the aggregate surfaces. Accordingly, in urban areas and other areas within speed limits, the microtexture properties of the surface are of primary concern (**Taylor and Francis Group, 2006**).

The macrottexture of the pavement surface refers to the coarser texture defined by the shape of the individual aggregate chips and by the spaces between the individual aggregate chips. Macrottexture is particularly

important in relation to wet conditions. In traditional surfacing materials, the individual aggregate chips provide a capability to penetrate a water film on the pavement surface, while the spaces between the aggregate chips provide drainage paths for the water to be dispersed.

The particles protruding above the plane of the surface provide positive macrotexture. This type of positive texture is provided in the various forms of surface dressing, specialist surfacing such as Hot Rolled Asphalt, and in the texture provided by brushing a concrete surface for example **(Taylor and Francis Group, 2006)**.

In all cases, the aim is to provide sufficient macrotexture to allow a safe and rapid dispersion of water away from the interface of tire surface and pavement surface. Macrotexture is the dominant factor in providing adequate frictional resistance at higher vehicle speeds (>50 km/h). However, it must be emphasized that microtexture does have some influence on frictional resistance at higher speeds, and macrotexture also has an influence at lower speeds.

A recent study in the U.K. emphasizes this, pointing out that the level of high-speed friction of surfacing depends on the microtexture, which provides low-speed friction and also that texture depth (a measure of macrotexture) has an impact on friction loss at low speeds. This is an important point as traditionally it has been assumed that measurement of macrotexture in urban and other low-speed locations is not important **(Roe et al., 1998)**.

### **2.5.2 Pavement Surface Material Properties**

Pavement material properties (i.e., aggregate and mix characteristics, surface texturings) influence both micro-texture and macro-texture. These properties also affect the long-term durability of texture through their capacities to resist aggregate polishing and abrasion/ wear of both

aggregate and mix under accumulated traffic and environmental loadings (Hall, 2006).

#### 2.5.2.1 Water Content

The water content is imperative for the bonding to occur between the aggregate. A water-cement ratio higher than the optimum will not create an adequate bond between the cement paste and aggregate causing the cement paste to run off the aggregate particles. If the water-cement is lower than the optimum, the cement paste will not be sufficiently adhesive to bond the aggregate (Harber, 2005).

#### 2.5.2.2 Effects of Finishing

Concrete finishing is a critical step in the paving process. Concrete finishing is the hand finishing that is typically applied to obtain a smooth surface necessary to correct any unevenness behind the paver. Excessive hand finishing will work water to the surface and can affect surface smoothness and concrete durability (Okamoto, et al, 2003). Examples of good and poor finishing practices are shown in Figure 2.5.

The brushing offered better skid resistance as compared to troweling, as indicated by the higher pendulum measurements. Moreover they provided more resistance against the effects of water with a lower decrease in the pendulum measurements as compared to troweling. Under wet condition, the adhesive component of friction governed by microtexture diminished. The texture created by brushing provided a channel for water to be drained, thereby maintaining the contact between the rubber slider and the test specimen (Yang, 2003).

To study the effects of the brushing as compared to troweling. The ratios indicated that the effects were more significant under wet condition

than at dry condition. With brushing, the pendulum readings were about 1.1 and 1.8 times that of troweling under dry and wet conditions respectively. The higher values exhibited under wet condition were expected since the effect of macrotexture was more effective for brushing(Yang, 2003).



**b. Poor practice**



**a. Good practice**

**Figure 2.5: Finishing operations (hand finishing and addition of additional material must be kept to a minimum)**

### 2.5.3 Slip Speed

The coefficient of friction between a tire and the pavement changes with varying slip. It increases rapidly with increasing slip to a peak value that usually occurs between 10 and 20 percent slip. The friction then decreases to a value known as the coefficient of sliding friction, which occurs at 100 percent slip **(Hall, 2006)**.

### 2.5.4 Tire Tread Design and Condition

Tire tread design (i.e., type, pattern, and depth) and condition have a significant influence on draining water that accumulates at the pavement surface. Water trapped between the pavement and the tire can be expelled through the channels provided by the pavement macro-texture and by the tire tread. Tread depth is particularly important for vehicles driving over thick films of water at high speeds. Some studies **(Henry, 1983)** have reported a decrease in wet friction of 45 to 70 percent for fully worn tires as compared to new ones.

### 2.5.5 Tire Inflation Pressure

High inflation pressure causes only a small loss of pavement friction, whereas low inflation pressure can significantly reduce friction at high speeds. This is because of the constriction of drainage channels within the tire tread and reduced contact pressure **(Henry, 1983)**.

### 2.5.6 Weather

Seasonal effects also can have a very significant role on the frictional resistance provided by a given pavement surface. The frictional resistance of a wet road surface is greater in winter than in summer **(Taylor and Francis Group, 2006)**.

The main difference between summer and winter conditions relates to changes in microtexture. It is believed that in dry summer conditions, heavy traffic polishes the aggregate faces using dust and other fine

materials on the road. In wet conditions, the dust is washed away, and in wet winter conditions, the presence of salt and grit works to improve the microtexture. As this polishing action involves traffic, and in particular heavy commercial vehicles, greater volumes of traffic on a particular road section will lead to greater variation in skid resistance over an annual cycle. Higher volumes of heavy vehicles also generally lead to lower average skid resistance values compared to similar surfaces carrying lower volumes of traffic ((**Taylor and Francis Group, 2006**).

However, skid resistance properties deteriorate when vehicle speeds increase. In this scenario, the hysteretic friction is reduced because a water film is developed between the vehicle tire and the pavement surface thus decreasing skid resistance, and potentially causing hydroplaning even when friction levels are adequate (**Noyce, 2007**).

Increasing macrotexture is one method to help decrease crash occurrence in wet weather pavement conditions. Moreover, a recent European study reports that increased macrotexture reduces total crashes under both wet and dry pavement conditions (**Roe et al, 1998**). This study also shows that increased macrotexture reduces crashes at lower speeds than previously believed.

### 2.5.7 Water Film Thickness

As previously mentioned, maintaining good skid resistance is very important in wet conditions for traffic safety. Drainage plays an important role in the mitigation of hydroplaning, since these problem tend to depend on the water film thickness (WFT) on the pavement. Figure 2.7 provides a definition of the WFT as it flows across the pavement surface (**Anderson, 1998**).

In Figure 2.6, the thickness of the water film that contributes to hydroplaning is the mean texture depth MTD plus the thickness of the water film above the top of the surface asperities. Water below the MTD is trapped in the surface and does not contribute to the drainage of the pavement. Drainage or flow occurs in the total flow layer,  $y$ , which is the water film thickness plus the mean texture depth. Increasing the depth (macrotexture) is important because it allows a reservoir for water (depth below the MTD) and enhances the water flow (depth above the MTD).

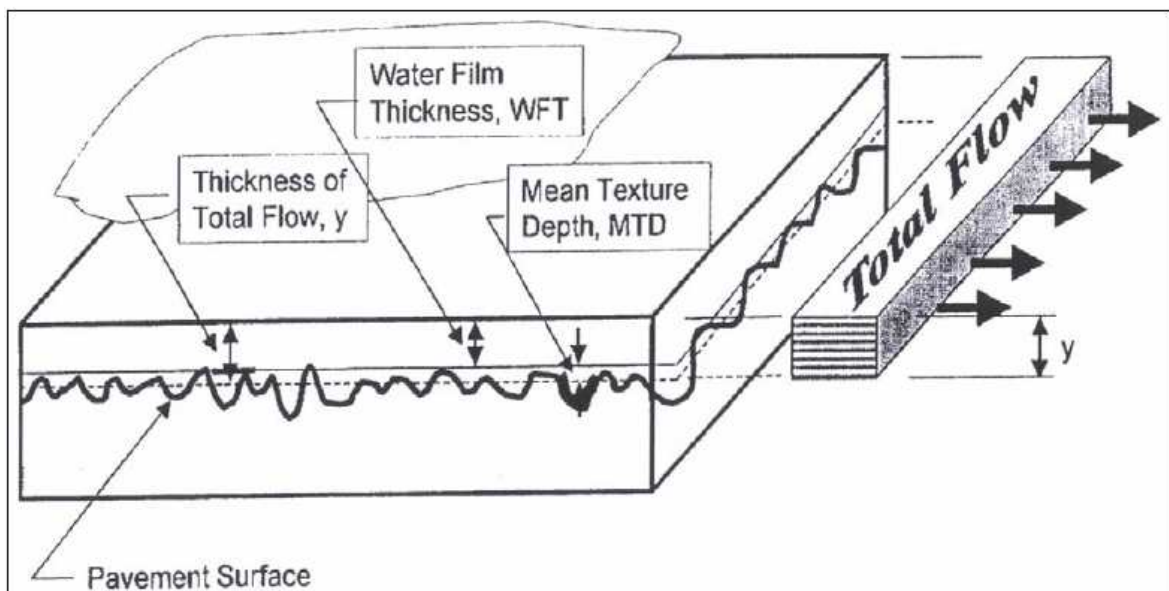


**Figure 2.6: Definition of WFT, MTD, and Total Flow (Noyce, 2007).**

The flow path for a particle of water falling on a pavement surface is simply defined as the line determined by the slope along the pavement surface. Thus, the maximum flow path for a pavement section is the longest flow path for the section. This is the maximum distance that a rainfall droplet can flow between the point of contact with the water film and its point of exit from the pavement.

Methods for Reducing Water Film Thickness - Reducing WFT is important for the safety of motorists avoiding hazardous situations,

particularly hydroplaning. Some of the techniques developed to reduce WFT are:

- Alteration of surface geometry;
- Installation of drainage appurtenance;
- Use of permeable or porous asphalt paving mixtures;
- Grooving in Portland cement concrete; and
- Enhancement of surface texture through mixture selection and design.

### 2.5.8 Other Elements Affecting Skid Resistance

In addition to climate and water in the pavement, Harwood et al. stated that the potential for a skidding crash depends mainly on the speed of the vehicle (frictional demand increases with the square of the speed), the cornering path, the magnitude of acceleration or braking, **(Harwood, 1980)**. On wet pavements, speed is the most significant parameter because the skid resistance at the tire-pavement interface decreases with increasing speed.

Temperature also exerts a considerable influence on the variability in skidding resistance results. Resistance to skidding tends to decrease as the temperature increases, due mainly to temperature effects on the material properties of the vehicle tires. This further increases the pattern of skidding resistance being lower in the summer than in the winter **(Kieran Feighan, 2006)**.

The age of the pavement surface can also be a significant factor. New pavement surfaces relying on exposed aggregate faces for skid resistance provision tend to polish under traffic action most rapidly **(Kieran Feighan, 2006)**.

Generally, it appears that adequate macrotexture depth helps in providing a higher level of friction; however, the available friction is

reduced as vehicle speed increases, as previously mentioned. It should be kept in mind that the need for adequate macrotexture does not diminish the need for high microtexture in the surface of pavements. In addition, poor microtexture and increasing water film thickness are detrimental in the skid resistance provision.

## **2.6 Concrete Materials Characteristics with Influence on Pavement Performance**

PCC properties affecting pavement performance, three key properties were identified. They include PCC compressive strength, tensile strength and elastic modulus.

Table 2.5 identifies for each of the key PCC properties (and aggregate interlock), the PCC mix characteristics which have been found to have a significant influence on these properties. The mix characteristics are coarse aggregate characteristics, w/c ratio, cement type and content and mineral additives. The category for coarse aggregate is fairly broad as it spans from aggregate size, type, gradation, hardness, angularity, soundness to environmental exposure, and reactivity (**Hansen et al ,2001**).

Water/cement ratio and coarse aggregate characteristics are the most important PCC mix characteristics from the viewpoint of PCC mechanical properties and in turn Jointed Plain Concrete Pavement (JPCP) structural performance. Water/cement ratio is the most important mix characteristics when considering PCC and JPCP durability. The following sections briefly discuss each of the properties listed in Table 2.5.

**Table 2.5: Primary variables affecting PCC properties (Hansen, et al ,2001).**

| PCC PROPERTY           | COARSE AGGREGATE CHARACTERISTICS* | W/C RATIO | CEMENT TYPE AND CONTENT | MINERAL ADDITIVES |
|------------------------|-----------------------------------|-----------|-------------------------|-------------------|
| Compressive Strength   | X                                 | X         | X                       | X                 |
| Split Tensile Strength | X                                 | X         |                         |                   |
| Elastic Modulus        | X                                 | X         |                         |                   |

\* Coarse aggregate size, angularity, gradation, content, and type.

### 2.5.1 Splitting Tensile Strength

Splitting tensile strength are properties directly related to the performance of PCC pavements. The PCC tensile characteristics directly affect the initiation of transverse cracking and corner breaks. Limited literature exists on the effect on tensile strength as the compressive strength increases. It is believed that the material characteristics, in general, affect the tensile properties in a similar manner as the compressive strength. Suggests that factors determining the aggregate-matrix bond are more important to PCC tensile capacity than compressive strength even in the normal strength range (Hansen et al ,2001).

### 2.5.2 Compressive Strength

Although compressive failure rarely occurs in the pavement structure, the compressive strength of concrete is perhaps the most comprehensive measure of concrete quality. The compressive strength is directly related to the microstructure of the hardened concrete. Higher

strength concrete behaves increasingly as a homogeneous material in pre-peak loading, where the propagation of microcracks does not initiate until just prior to failure. The compressive strength is mainly related to the w/c ratio. As the w/c ratio decreases, the compressive strength increases .

Furthermore, strength of the coarse aggregate and quality can become controlling factors at high compressive strengths. In addition, aggregate type influences the characteristics of the aggregate-paste bond .

Increasing aggregate size generally decreases the water requirements for the same consistency, and should thereby also benefit the strength of the concrete. **(Hansen et al ,2001).**

### **2.5.3 Elastic Modulus**

The PCC elastic modulus is an important variable in pavement design as it controls the overall slab deflection from traffic loading and the slab curling stresses. The elastic modulus increases as the compressive strength increases, and it is found that in general the material characteristics affect the elastic modulus in the same manner as the compressive strength. It should be noted that aggregate type and gradation have strong influence on the elastic modulus **(Hansen et al ,2001).**

## **2.7 Fundamental of Tire-Pavement Noise**

### **2.7.1 Sound Measurement Unit**

Sound can be determined by two characteristics: frequency and amplitude. Frequency is a measure of the number of vibrations that occur in one second. Frequency is measured in Hertz (Hz) and is known as pitch. The wavelength of any sound is the measurement of shortest repetition length for sound waves or the distance from rarefaction to rarefaction or

compression to compression. The relationship between frequency and wavelength depends on the speed of sound in air, which is indicated in Equation 2.9.

$$c = f\lambda \quad \text{-----2.9}$$

where  $f$  and  $\lambda$  represent frequency (Hz) and wavelength (m), respectively.  $c$  (m/s) represents the speed of sound in air. The speed of sound depends on the air temperature ( $^{\circ}\text{C}$ ),  $T$ , which is indicated in Equation 2.10. For instance, the speed of sound at  $20^{\circ}\text{C}$  is approximately 343 m/s.

$$c = 331.4 + 0.6T \quad \text{-----2.10}$$

The amplitude of a sound wave refers to the loudness or the sound pressure level and it is measured in decibels (dB). Decibel is a logarithmic scale that is based on the logarithm of a ratio of the pressure to a reference pressure. The sound pressure level is also referred to the sound level or the noise level that is shown in Equation 2.11:

$$\text{SPL} = 20 \cdot \log_{10} \left( \frac{p}{p_o} \right) \quad \text{-----2.11}$$

where SPL represents the sound pressure level (dB). The reference pressure,  $P_o$ , refers to a typical threshold of human hearing,  $2 \times 10^{-5} \text{ N/m}^2$ .  $P$  refers to the air pressure level ( $\text{N/m}^2$ ) caused by the vibration object (**Yuen-Ting,2007**).

Typically, a human with good hearing can perceive sound between 20 Hz to 20,000 Hz. However, human ears are not equally sensitive to all frequencies. Thus, three sound level weighting networks were introduced in order to simulate the human perception of sounds. The three weighting networks are A-weighting [dBA or dB(A)], B-weighting [dBB or dB(B)],

and C-weighting [dBC or dB(C)]. These curves are shown in Figure 2.7 (Bies and Hansen,2003).

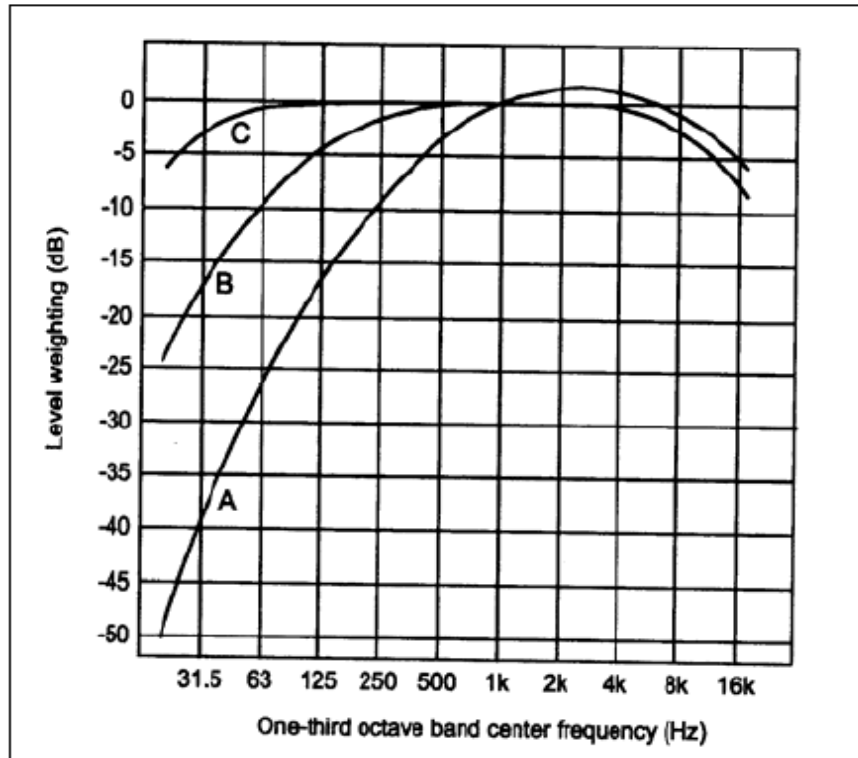


**Figure 2.7: A-, B- and C-weighting Curves for Sound Level Meters (Bies and Hansen,2003).**

The A-weighting network is designed to approximate the response of the human ear, at moderate amplitudes, to typical environmental noise. The A-weighting network has been widely adopted for noise measurement standards and in many sound level meters to mimic the response of the human ear to sound. B-weighting and C-weighting networks are available for weighting sound at higher amplitudes than are typical of environmental noise (e.g. industrial noise). The decibel scale ranges from threshold of hearing 0 dBA to the pain threshold 140 dBA approximately. It is not simple to quantify loudness without an actual measurement. Therefore, Table 2.6 demonstrates the Sound Pressures and their accompanying SPL (Yuen-Ting,2007).

**Table 2.6: Typical Sound Pressures and Sound Pressure Levels**

| Apparent loudness | Sound Pressure<br>(m Pa) | Sound Pressure<br>Level (dB) | Source               |
|-------------------|--------------------------|------------------------------|----------------------|
| Deafening         | 200,000,000              | 140                          | Jet aircraft         |
|                   |                          | 130                          | Pain threshold       |
| Very loud         | 20,000,000               | 120                          | Loud horn at 1 m     |
|                   | 2,000,000                | 100                          | Noisy factory        |
|                   | 200,000                  | 80                           | Noisy office         |
| Loud              | 20,000                   | 70                           | Average street noise |
|                   |                          | 60                           | Average office       |
| Moderate          | 2200                     | 40                           | Private office       |
| Faint             | 200                      | 20                           | Rustling leaves      |
|                   |                          | 10                           | Normal breathing     |
| Very faint        | 20                       | 0                            | Hearing threshold    |

### 2.7.2 Tire-Pavement Noise Generation Mechanism

Tire-pavement noise generation mechanisms can be divided into two main groups: mechanical vibrations of the tire and aerodynamical phenomena. Noise generated by the mechanical vibration of the tire is known as structure-borne noise, which include the impact and adhesion mechanisms. Aerodynamical phenomena include air displacement is air-borne noise (Sandburg and Ejsmont,2002).

### 2.7.2.1 Impact Mechanism

The impact between the tire tread block and the pavement surface causes radial vibrations and also causes tangential vibrations in both the tire tread and tire belt as shown in Figure 2.8 (Haddock. et. al.2004).

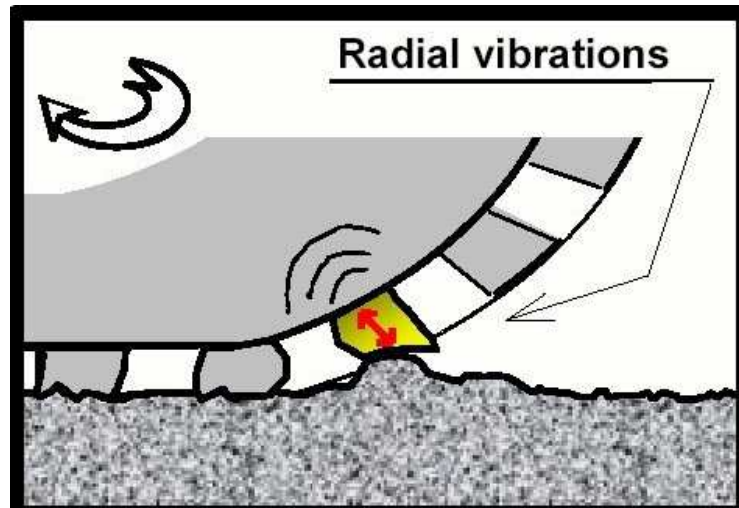


Figure 2.8: Vibration caused by tread block/pavement impact (Haddock. et. al.2004).

### 2.7.2.2 Adhesion Mechanism

When a tire rolls over the pavement, the tire tread block can adhere to the pavement surface then snap and/or slip before breaking away of the pavement surface. These stick-snap and stick-slip phenomena cause the tire to vibrate and generate sound after the tire releases from the pavement as shown in Figure 2.9 (Haddock. et. al.2004).

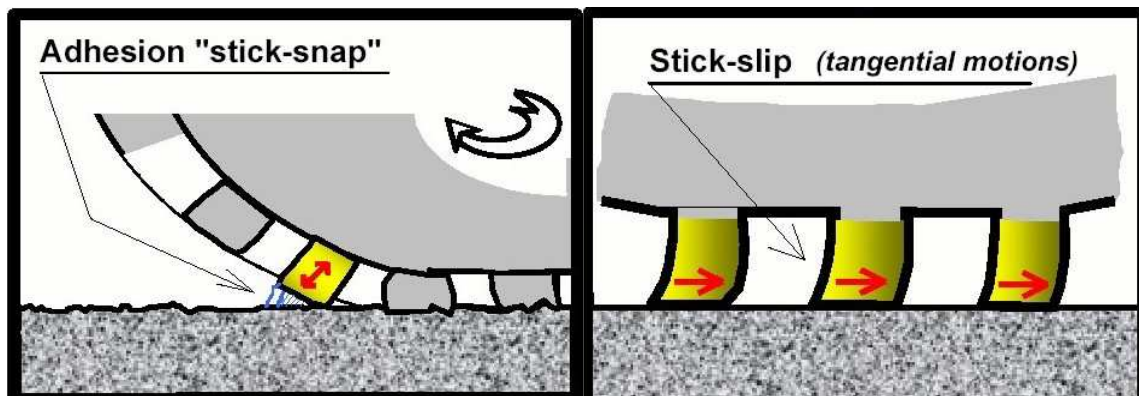


Figure 2.9 Adhesion between the tread block and pavement at the exit of the contact patch (Haddock. et. al.2004).

### 2.7.2.3 Air Displacement Mechanism

It is related to the air movement around the tire. Air is pumped into the cavities between the tire tread and road surface, compressed by the tire weight, and then pumped out from cavities during the rolling movement. The compression-release of air acts as a pump that generates sound, also known as air pumping as shown in Figure 2.10 (Haddock. et. al.2004).

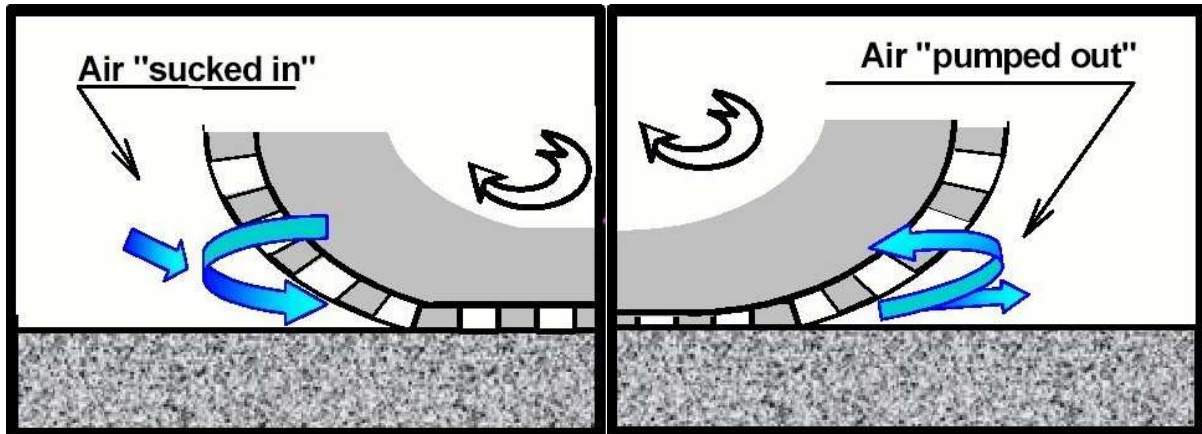


**Figure 2.10: Air pumping at the entrance and exit of the contact patch (Haddock. et. al.2004).**

The geometry of the tire and pavement can also enhance noise generation. This is similar to sound generated by musical instruments. For instance, the geometry of the tire above the pavement acts as a horn to amplify noise generated by the air pumping and the tread vibration. Air in the tread cavity vibrates and produces sound similar to a whistle(Haddock. et. al.2004).

Tire-pavement noise can also be reduced or attenuated by the surface texture and sound absorption properties of the pavement mix. A porous pavement surface creates more noise than a smooth pavement surface, but it also absorbs more noise than the smooth surface. This absorption results from the fact that air is squeezed into void spaces in the pavement rather than being compressed, reducing the quantity of noise that can propagate to a far field receiver (DDCL,2006).

### 2.7.3 Traffic Sound Level Measuring Method

The quality of road surfaces, in terms of sound attenuation ability, can be quantified by measuring the traffic sound level. Pass-By Method (PBM) is standardized sound level measurement technique for measuring traffic sound levels in the field.

In fact, the size of the vehicle in a traffic stream affects the traffic sound level. Generally, sizes of vehicles are categorized by the number of axles and the weight. A larger vehicle will cause a higher traffic sound level. A summary of the vehicle category for the International Organization for Standardization (ISO), the Ontario Ministry of the Environment (MOE), and the U.S. Federal Highway Administration (FHWA) is shown in Table 2.8 (ISO,1997, Schroter,1989 and Lee,1996).

**Table 2.7: Vehicle Categories**

| Specifications                                            | Vehicle Category |       |             |
|-----------------------------------------------------------|------------------|-------|-------------|
|                                                           | MOE              | ISO   | FHWA        |
| 2-axle, 4 wheels, $\leq 9$ passengers, $\leq 4500$ kg     | Car/Light        | Car   | Automobiles |
| 2-axle, 6 wheels, 4500 to 12000 kg                        | Medium           | Heavy | Medium      |
| $\geq 3$ -axle, design for hauling cargo, $\geq 12000$ kg | Heavy            |       | Heavy       |

#### Pass-By Method

The PBM is a mean of assessing noise or sound at a distance. This method is conducted by placing a sound measurement system (i.e. microphone and sound level meter or similar instrument) at a defined distance from the vehicle path offset from the centreline. It measures the A-weighted sound pressure level (SPL, in dBA) of vehicle passing by. The measured sound level includes all noise generated by the vehicle, including

noise generated by the tire-pavement, powertrain, and aerodynamic. Two pass-by methods are used to measure the roadside traffic sound level: the Statistical Pass-By (SPB) Method and the Controlled Pass-By (CPB) Method. The purpose of these two methods is to compare or evaluate traffic noise on different road surfaces (**Yuen-Ting,2007**).

### 1) Statistical Pass-By (SPB) Method

The Statistical Pass-By (SPB) Method procedures are defined by both the International Organization for Standardization ISO: 11819-1:1997 “Acoustics – Measurement of the Influence of Road Surface on Traffic Noise – Part 1: Statistical Pass-By Method” and the FHWA Measurement of Highway-Related Noise Manual. The SPB Method is used to measure the roadside sound level from a variety of road traffic (i.e. the free-flowing traffic condition). In addition, the pavement quality, such as condition, age, or the condition before and after resurfacing, can be monitored and evaluated (**Yuen-Ting,2007**).

In the SPB Method, the A-weighted sound pressure level (SPL) is measured at a specified road-side location which is indicated in Figure 2.11.

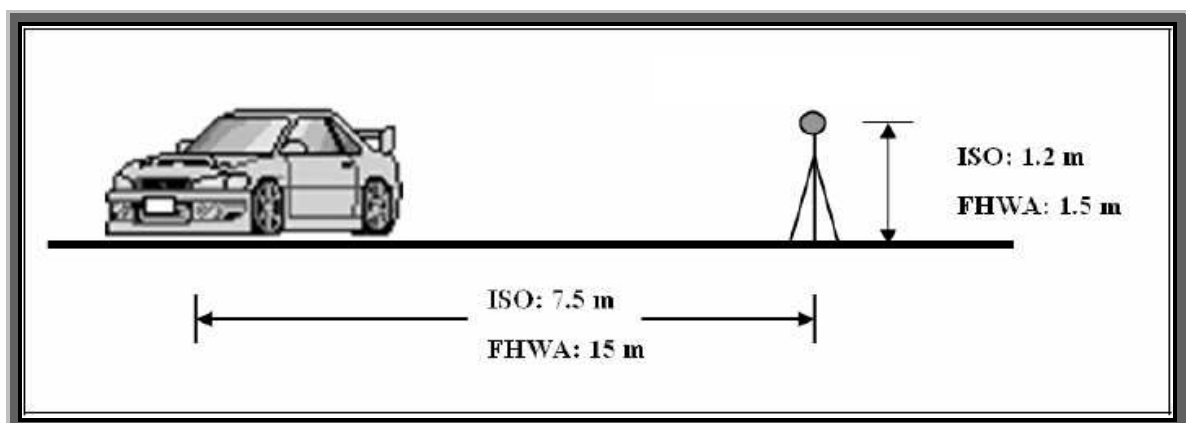


**Figure 2.11: Microphone Position for the Pass-By Method**

The ISO standard suggests locating the microphone 7.5 m away from the centerline of the travel lane horizontally and 1.2 m above the plane of the road lane **(ISO,1997)**. FHWA manual suggests placing the microphone 15 m (50 ft) away and 1.5 m (5 ft) above the ground. Both standards require recording the traffic count, vehicle speeds and sizes during the measurement. These data are used to compute a Statistical Pass-By Index (SPBI) and that Index is used to compare the sound level of various pavement types at different locations. Usually, the traffic data collection is recorded by a traffic counting device, video camera, and speed radar **(Lee,1996)**.

## **2) Controlled Pass-By (CPB) Method**

The Controlled Pass-By (CPB) Method has the same measurement setup as the SPB Method as mentioned in Section (1). However, the difference is that it measures the sound level produced by a single vehicle or multiple selected vehicles, rather than from the normal free-flowing traffic stream **(Sandberg,2002)**.

The CPB Method is appropriate for:

- \* Comparing sound level between pavements
- \* Evaluating long-term performance of pavement

However, the disadvantage of the CPB Method is that it requires the temporary closure of the road during testing. This will affect the short-term traffic flow, especially in urban areas.

Therefore, SPB Method is favorable to be used in urban areas, while the CPB Method is preferred in rural areas.

## CHAPTER THREE

# **Materials and Methods Of Testing**

# Chapter 3

## Materials and Methods of Testing

In this chapter, the details of experimental program of present work are presented. It includes details of materials used, specimens preparation and tests procedure which are:

1. Marshall Test.
2. Volumetric Method.
3. British Pendulum Tester.
4. Compressive Strength Test.
5. Splitting Tensile strength Test.
6. Static Modulus of Elasticity Test.

### 3.1 Materials

The materials used in this work are locally available in Iraq. The properties are evaluated according to ASTM standards compared with the State Corporation of Roads and Bridges (SCRB/R9, 2003) specification requirements.

#### 3.1.1 Flexible Pavement

##### 3.1.1.1 Asphalt Cement

One grade of asphalt cement (40–50) penetration graded from Al-Dourah refinery is used. The physical properties and tests of the used asphalt cement are shown in Table (3.1).

**Table (3.1) :The Physical Properties and Tests of the Used Asphalt Cement.**

| <b>Property</b>                                           | <b>ASTM Designation</b> | <b>Test Result</b> | <b>SCRB /R9 Specifications</b> |
|-----------------------------------------------------------|-------------------------|--------------------|--------------------------------|
| <b>Penetration</b><br>(25 °C, 100 gm, 5 sec),<br>(0.1 mm) | D-5                     | 43                 | (40 – 50)                      |
| <b>Kinematic Viscosity</b><br>at 135 °C, (cst).           | D-2170                  | 405                |                                |
| <b>Ductility</b><br>(25 °C, 5 cm/min).<br>(cm)            | D-113                   | 107                | > 100                          |
| <b>Flash Point</b><br>(Cleveland open cup)<br>,(°C)       | D-92                    | 275                | min. 232                       |
| <b>Specific , Gravity at</b><br>25 °C                     | D-70                    | 1.055              | .....                          |
| <b>After Thin Film Oven Test</b>                          |                         |                    |                                |
| <b>Penetration of Residue</b><br>(25 °C, 100 gm, 5 sec)   | D-5                     | 33                 |                                |
| <b>Ductility of Residue,</b><br>cm,(25°C,5 cm/min)        | D-113                   | > 20               |                                |

### **3.1.1.2 Aggregate**

The source of the aggregate used in this work is Al-Niba'ee quarry. This aggregate is widely used in Iraq for asphalt mixtures works. Three gradations are selected for aggregate for maximum size of (12.5, 19, 25 mm) with different percentages of filler as shown in Tables (3.2), (3.3) and (3.4). The physical properties are summarized in Table (3.5).

### **3.1.1.3 Filler**

In this study, mineral filler have been used including limestone dust from lime factory in Karbala governorate. The physical properties of this filler is presented in Table (3.6).

**Table (3.2) :Asphalt Mixture Gradings for normal maximum size of (12.5 mm).**

| <b>Sieve</b>                                          |                      | <b>Gradings of Surface<br/>(Wearing) Course<br/>(% Passing by Weight of Total<br/>Aggregate + Filler)</b> |                          |                        | <b>Specification<br/>Limits<br/>SCRB /R9</b> |
|-------------------------------------------------------|----------------------|-----------------------------------------------------------------------------------------------------------|--------------------------|------------------------|----------------------------------------------|
| <b>Opening<br/>(mm)</b>                               | <b>Size<br/>(in)</b> | <b>Lower<br/>Limit</b>                                                                                    | <b>Average<br/>Limit</b> | <b>Upper<br/>Limit</b> |                                              |
| 12.5                                                  | 1/2                  | 100                                                                                                       | 100                      | 100                    | 100                                          |
| 9.5                                                   | 3/8                  | 90                                                                                                        | 95                       | 100                    | 90-100                                       |
| 4.75                                                  | No.4                 | 55                                                                                                        | 70                       | 85                     | 55-85                                        |
| 2.36                                                  | No.8                 | 32                                                                                                        | 50                       | 67                     | 32-67                                        |
| 300 um                                                | No.50                | 7                                                                                                         | 15                       | 23                     | 7-23                                         |
| 75 um                                                 | No.200               | 4                                                                                                         | 7                        | 10                     | 4-10                                         |
| <b>Asphalt Cement<br/>(% weight of total<br/>mix)</b> |                      | 4-6                                                                                                       | 4-6                      | 4-6                    | 4-6                                          |

Table (3.3) :Asphalt Mixture Gradings for normal maximum size of (19 mm).

| <b>Sieve</b>                                          |                      | <b>Gradings of Surface<br/>(Wearing) Course<br/>(% Passing by Weight of Total<br/>Aggregate + Filler)</b> |                          |                        | <b>Specification<br/>Limits<br/>SCRB /R9</b> |
|-------------------------------------------------------|----------------------|-----------------------------------------------------------------------------------------------------------|--------------------------|------------------------|----------------------------------------------|
| <b>Opening<br/>(mm)</b>                               | <b>Size<br/>(in)</b> | <b>Lower<br/>Limit</b>                                                                                    | <b>Average<br/>Limit</b> | <b>Upper<br/>Limit</b> |                                              |
| 19                                                    | 3/4                  | 100                                                                                                       | 100                      | 100                    | 100                                          |
| 12.5                                                  | 1/2                  | 90                                                                                                        | 95                       | 100                    | 90-100                                       |
| 9.5                                                   | 3/8                  | 76                                                                                                        | 83                       | 90                     | 76-90                                        |
| 4.75                                                  | No.4                 | 44                                                                                                        | 59                       | 74                     | 44-74                                        |
| 2.36                                                  | No.8                 | 28                                                                                                        | 43                       | 58                     | 28-58                                        |
| 300 um                                                | No.50                | 5                                                                                                         | 13                       | 21                     | 5-21                                         |
| 75 um                                                 | No.200               | 4                                                                                                         | 7                        | 10                     | 4-10                                         |
| <b>Asphalt Cement<br/>(% weight of total<br/>mix)</b> |                      | 4-6                                                                                                       | 4-6                      | 4-6                    | 4-6                                          |

**Table (3.4) :Asphalt Mixture Gradings for normal maximum size of (25 mm).**

| <b>Sieve</b>                                          |                      | <b>Gradings of Surface<br/>(Wearing) Course<br/>(% Passing by Weight of Total<br/>Aggregate + Filler)</b> |                          |                        | <b>Specification<br/>Limits<br/>SCRB /R9</b> |
|-------------------------------------------------------|----------------------|-----------------------------------------------------------------------------------------------------------|--------------------------|------------------------|----------------------------------------------|
| <b>Opening<br/>(mm)</b>                               | <b>Size<br/>(in)</b> | <b>Lower<br/>Limit</b>                                                                                    | <b>Average<br/>Limit</b> | <b>Upper<br/>Limit</b> |                                              |
| 25                                                    | 1                    | 100                                                                                                       | 100                      | 100                    | 100                                          |
| 19                                                    | 3/4                  | 90                                                                                                        | 95                       | 100                    | 90-100                                       |
| 12.5                                                  | 1/2                  | 70                                                                                                        | 80                       | 90                     | 70-90                                        |
| 9.5                                                   | 3/8                  | 56                                                                                                        | 68                       | 80                     | 56-80                                        |
| 4.75                                                  | No.4                 | 35                                                                                                        | 50                       | 65                     | 35-65                                        |
| 2.36                                                  | No.8                 | 23                                                                                                        | 36                       | 49                     | 23-49                                        |
| 300 um                                                | No.50                | 5                                                                                                         | 12                       | 19                     | 5-19                                         |
| 75 um                                                 | No.200               | 4                                                                                                         | 7                        | 10                     | 4-10                                         |
| <b>Asphalt Cement<br/>(% weight of total<br/>mix)</b> |                      | 4-6                                                                                                       | 4-6                      | 4-6                    | 4-6                                          |

Table (3.5) : Physical Properties of the Used Aggregate.

| Property                  | ASTM Designation    | Course Aggregate | Fine Aggregate |
|---------------------------|---------------------|------------------|----------------|
| Bulk Specific Gravity     | C-127<br>&<br>C-128 | 2.63             | 2.63           |
| Apparent Specific Gravity | C-127<br>&<br>C-128 | 2.68             | 2.76           |
| % Water Absorption        | C-127<br>&<br>C-128 | 0.5              | 2.8            |

Table ( 3.6 ) : Physical Properties of the Used Type of Filler.

| Property                        | Filler Type    |
|---------------------------------|----------------|
|                                 | Limestone Dust |
| Specific Gravity                | 2.67           |
| Passing Sieve No.200 (0.075 mm) | %94            |

### 3.1.2 Rigid Pavement

#### 3.1.2.1 Cement

Ordinary Portland cement (O.P.C) manufactured by cement plant of karbalaa was used throughout this investigation. This cement complied with the Iraqi specification IQS No.5/1984. It was kept in laboratory and stored in a dry place. The physical properties and chemical composition of this cement are given in Tables 3.7& 3.8 respectively as tested in cement test laboratory/ civil engineering department/ Babylon University.

#### 3.1.2.2 Fine aggregate

Graded sand brought from Al-Akhader in Karbala governorate is used in this study. It was washed and left in laboratory to dry. Table 3.9 shows the sieve analysis, according to IOS 45:1984 specification.

**Table 3.7: Physical characteristics of cement.**

| Physical properties                                                                                                                                                   | Test results | Limit of Iraqi specification<br>IQS No.5/1984 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|-----------------------------------------------|
| <ul style="list-style-type: none"> <li>Setting Time, min      Initial</li> <li>                                         Final</li> </ul>                              | 125<br>230   | ≥ 45 min<br>≤ 600 min                         |
| <ul style="list-style-type: none"> <li>Fineness (Blain Method) in<br/>cm<sup>2</sup>/gm</li> </ul>                                                                    | 2800         | ≥ 2500                                        |
| <ul style="list-style-type: none"> <li>Compressive strength :</li> <li>in MPa      at      3 days</li> <li>                                         7 days</li> </ul> | 15.1<br>23.3 | ≥ 15<br>≥ 23                                  |

**Table 3.8: Chemical composition and main compounds of ordinary Portland cement**

| Oxide                                        | Content %                 | Limits according to IQS No.5/1984                                    |
|----------------------------------------------|---------------------------|----------------------------------------------------------------------|
| SiO <sub>2</sub>                             | 12.21                     | -----                                                                |
| CaO                                          | 64.66                     | -----                                                                |
| MgO                                          | 1.42                      | <= 5%                                                                |
| Fe <sub>2</sub> O <sub>3</sub>               | 5.12                      | -----                                                                |
| Al <sub>2</sub> O <sub>3</sub>               | 3.8                       | -----                                                                |
| SO <sub>3</sub>                              | 2.03                      | <= 2.5% if C <sub>3</sub> A < 5%<br><= 2.8% if C <sub>3</sub> A > 5% |
| Free lime                                    | 1.23                      | -----                                                                |
| Loss of Ignition                             | 1.23                      | <= 4%                                                                |
| Insoluble Residue                            | 0.79                      | <= 1.5%                                                              |
| L . S . F                                    | 0.92                      | 0.66 – 1.02                                                          |
| <i>Main compounds<br/>(Bogue's equation)</i> | <i>% by wt. of cement</i> |                                                                      |
| C <sub>3</sub> S                             | 59.07                     |                                                                      |
| C <sub>2</sub> S                             | 15.99                     |                                                                      |
| C <sub>3</sub> A                             | 1.40                      |                                                                      |
| C <sub>4</sub> AF                            | 15.58                     |                                                                      |

**Table 3.9: Sieve analysis and some properties of fine aggregate**

| <b>Sieve size<br/>(mm)</b> | <b>% Passing</b> | <b>Limit of Iraqi<br/>Specification<br/>No.45/1984</b> |
|----------------------------|------------------|--------------------------------------------------------|
| <b>10</b>                  | 100              | 100                                                    |
| <b>4.75</b>                | 95               | 100–90                                                 |
| <b>2.36</b>                | 80               | 95–60                                                  |
| <b>1.18</b>                | 67               | 70–30                                                  |
| <b>0.6</b>                 | 51               | 75–34                                                  |
| <b>0.3</b>                 | 21               | 20–5                                                   |
| <b>0.15</b>                | 4                | 10–0                                                   |
| <b>0.075</b>               | 0                | ≤5%                                                    |

### 3.1.2.3 Coarse aggregate

Graded gravel used in this study. It was brought from Al-Nibae – Baghdad with maximum aggregate size (25, 19, 12 mm). It was washed and left in laboratory to dry. Table 3.10 shows the sieve analysis.

### 3.1.2.4 Water

Ordinary drinking water was used throughout this work for both making and curing the specimens.

**Table 3.10: Gradation of gravel used in concrete mixes.**

| SIEVE        |                 | PERCENTAGE PASSING GIVEN SIEVE SIZE |                    |                    |
|--------------|-----------------|-------------------------------------|--------------------|--------------------|
| Opening (mm) | Size (in)       | 1 inch                              | $\frac{3}{4}$ inch | $\frac{1}{2}$ inch |
| 25           | 1"              | 100                                 | 100                | 100                |
| 19           | $\frac{3}{4}$ " | 85                                  | 100                | 100                |
| 12.5         | $\frac{1}{2}$ " | 67                                  | 75                 | 100                |
| 9.5          | $\frac{3}{8}$ " | 50                                  | 55                 | 35                 |
| 4.75         | NO.4            | 0                                   | 0                  | 0                  |
| 2.36         | NO.8            | 0                                   | 0                  | 0                  |

## 3.2 Methods of Testing

### 3.2.1 Marshall Test.

This test was carried out according to the ASTM (D1559) (ASTM, 2003) which covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface of the specimen by means of Marshall Apparatus. The Marshall stability is the maximum load the specimen can withstand before failure when tested in the Marshall stability test. The configuration of the Marshall stability test is close to that of the indirect tensile strength test, except for the confinement of the Marshall specimen imposed by the Marshall testing head. Thus, the Marshall stability is related to the tensile strength of the asphalt mixture.

The Marshall flow is the total vertical deformation of the specimen, in units of 0.01 in., when it is loaded to the maximum load in the Marshall Stability test. The Marshall flow can provide some indication of the resistance of an asphalt mixture to plastic deformation. Mixtures with low flow number are stiff and may be difficult to compact. However, these mixtures are more resistance to rutting than those with high flow numbers.

The percent of aggregate, percent of binder, percent air voids, stability, and flow were found for each prepared specimen, using ASTM standard methods. The Marshall stiffness was also determined for these specimens. The result and calculations are presented in chapter Four.

### **3.2.2 Skid resistance tests**

#### **3.2.2.1 Macrotexture Measurement (Volumetric Method):-**

Traditionally, texture depth measurements have been carried out as a measure of pavement macrotexture.

The sand patch or volumetric patch test is by far the most commonly prescribed test worldwide. It is covered in numerous national and international specifications including ASTM E965 (**ASTM, 2003**).

The test basically consists of a known volume of standardized sand or small glass spheres being spread out over the pavement surface using a flat disk. The sand are distributed to form a circular patch. A small circle diameter indicates a high average texture depth; a large circle diameter indicates a low average texture depth. The volume of sand (known) divided by the surface area covered by the sand (measured on site) yields the average texture depth. Plate 3.1 shows the volumetric patch test being carried out on site.



**Plate (3.1): Volumetric Method.**

**ASTM E965** points out that in spreading the material (sand or glass spheres), the surface voids are completely filled to the tips of the surrounding aggregate particles. The plane from which the texture depth is measured is effectively defined by the bottom surface of the spreading disk passing over the tips of the aggregate particles. The volumetric patch method is not suitable for pavements with large surface voids or for use on grooved surfaces.

The main advantage of the volumetric patch test is its simplicity. The equipment is relatively low-cost, the calculations of volume divided by area are straightforward, and results are immediately attainable. The main disadvantages are that the test is slow and labor-intensive, and the results are dependent on the skill of the technician to produce a circular surface area. Traditionally, Ottawa sand was used for spreading, hence the “sand patch” designation (**Kieran Feighan, 2006**).

Volumetric patch tests are still used as the standard in specifications worldwide. **ASTM E965** recommends that at least four random-spaced measurements of average texture depth be measured, and the arithmetic average value be used to characterize the pavement surface texture depth. Under the relevant British Standard (**BS 598-105, 1990**), five volumetric patch tests are carried out over a 50 m length, and the average value is used to represent the stretch.

### **3.2.2.2 Microtexture Measurement (British Portable Skid Resistance Tester ):-**

As already discussed, direct measurement of microtexture is not feasible due to the microscopic nature of the factors influencing differences between aggregate sources. On pavement surfaces, the polishing susceptibility of a particular stone under the scrubbing action of vehicle tires at the tire/surface interface is of primary interest.

The British Pendulum Tester is described in **ASTM E303 (ASTM E303-93)**. Basically, it consists of a swinging arm with a rubber slider base. The arm is released from a specified height, and allowed to swing down, acting as a pendulum. At the lowest point of the swing arc, the rubber slider comes in contact with a prepared surface of aggregate to be tested. Plate 3.2 shows British Pendulum Tester being carried out on site.

The greater the friction developed between the rubber slider and the test surface, the more the swing of the pendulum is retarded. A drag pointer attached to the pendulum arm indicates the height reached by the pendulum arm after it has dragged over the test surface. Lower height measurements indicate greater frictional resistance. The height measurements are read off as British Pendulum Number (BPN) values.

Effectively, the pendulum tester is measuring the energy loss when the rubber slider is propelled by a standard force (achieved by dropping a specified weight at the bottom of the swing arm from a specified height) across the test surface. Due to the slow speed of the dropping arm in conjunction with the properties of the rubber slider and the prepared test surface, the energy loss is directly related to the microtexture of the aggregate surface.



**Plate (3.2) : The British Pendulum Test.**

### **3.2.3 Concrete Testing**

#### **3.2.3.1 Compressive Strength Test**

The concrete compressive strength was measured on 150 mm cube by using the machine of compressive strength test (CONTROLS –MILANO-ITALY with 200 ton capacity). The cubes were removed from the curing

solution at age of 28 days. The reported values were the average of three specimens for each mix.



**Plate (3.3) : Compressive Strength Test.**

### 3.2.3.2 Splitting Tensile strength Test.

The concrete splitting tensile strength was measured on 100 \*200 mm cylinders by using the machine of compressive strength test according to **ASTM C 496-86 (ASTM C 496-86)**.

The cylinders were removed from the curing solution at age of 28 days. Splitting tensile strength can be calculated by using the following equation:

$$f_t = 2P / \pi DL \quad \text{-----3.1}$$

Where:

$f_t$  : splitting tensile strength (N/mm<sup>2</sup>).

P: applied load (N).

D: diameter of cylinder (mm).

L: length of cylinder (mm).

The reported values were the average measured on three specimens for each mix.

### 3.2.3.3 Static Modulus of Elasticity Test.

The static modulus of elasticity was determined with (150\*300 mm) according to **ASTM C-469** specification. The top surface of cylinder was well finished from irregularities and capped with cement pasts to avoid any loss of strength. The load was applied gradually and increased continuously at constant rate of 1.27 mm/min until 40% of the ultimate load. The compressometer used has a gauge length of 150 mm and gauge with an accuracy of 0.002 mm as shown in Plate (3.4).



Plate (3.4) : Static Modulus of Elasticity Test.

### 3.2.4 Noise level measurements

#### 3.2.4.1 Statistical Passby (SPB)

Statistical Passby (SPB) methods utilize a random sample of passenger car measured one at a time. The sound pressure level is captured for each passby using a sound measurement system such as a sound level meter (SLM). In Europe, the ISO Standard 11819-1 calls for placing microphones 7.5 m (25 ft) from the center of the traffic lane at a height of 1.2 m (4 ft) above the pavement. It also requires that the noise characteristics and speed of 180 vehicles be obtained **(Haddock. et. al.2004)**.

The FHWA procedure developed by the Volpe Transportation Systems Center calls for the placement of a microphone or microphones 15 m (50 ft) instead of 7.5 m (25 ft) from the center of the travel lane and microphone height of 1.5 m (5 ft). The FHWA procedure does not specifically state the number of vehicles required for a valid sample **(Haddock. et. al.2004)**.

A statistically significant sample of light and heavy vehicles must be collected. The data is used to compute a Statistical Passby Index (SPBI) which can be used to compare various pavements. SPB methods account for all aspects of traffic noise at the sideline of the highway including engine, tire/pavement and aerodynamic noise. The method also takes into account the variation that occurs across vehicles of the same type. However, the measurement is not tightly controlled since random vehicles will be involved at different sites, as shown in Figures (3.5 and 3.6).



**Figure (3.5) : Sound measurement sound level meter (SLM).**



**Figure (3.6) : Typical measurement set up for SPB measurement**

#### 3.2.4.2 Controlled Passby (CPB)

For controlled passby (CPB) measurements the same measurement setup as SPB is used. For CPB relatively selected vehicle is driven at a controlled speed past the measurement location. In some cases, to emphasize tire/pavement noise, the vehicle may coast past the measurement point (**Haddock. et. al.2004**).

Pavement alternatives are compared for each vehicle at each speed. European Union is currently developing a method for EU standardization, and possibly for ISO, based on a French national standard. In addition, vehicle noise measurement standards of this type, which are used for evaluating vehicles and tires on standard pavements.

The CPB method takes less time than the SPB method but does not account for the variation that might occur in vehicles of the same type. The method has the same site limitations as SPB and requires a light traffic density making it more suited to rural or test track conditions (**Haddock. et. al.2004**).

### 3.3 Properties of Mixtures

#### 3.3.1 Properties of Asphalt Concrete Mixture

In this study, the properties of asphalt concrete mixtures used in testing (Marshall Test, Volumetric Test and British portable Tester) are:

- Asphalt Cement Grade = (40-50).
- Filler Type = Limestone Dust.
- Mixing Temperature = (155-165) °C.
- Compaction Temperature = (130-140) °C.

The testing variables for asphalt concrete mixtures include the following:

- Aggregate maximum mineral size (25, 19 and 12.5 mm).
- Asphalt Content, AC% (4.1, 4.7, 5.3 and 6) %.
- Gradation Limit: (Fine, Intermediate, and Course).
- Surface condition (wet and dry).

### 3.3.2 Properties of Concrete Mixtures

In this study, the properties of concrete mixtures used in testing (compressive strength test, splitting tensile test, static modulus of elasticity test, Volumetric Test and British portable Tester) are:-

- karbalaa Cement.
- Mixing Temperature =30°C.
- Natural Aggregate.

The testing variables for concrete mixtures include the following:

- Water/Cement ratio (0.45, 0.55 and 0.65).
- Aggregate Maximum Size (1", ¾" and ½").
- Cement: Sand: Gravel ratio (1:1.5:3, 1:2:4 and 1:3:6).
- Finishing (Smooth and Rough).
- Surface condition (wet and dry).

## 3.4 Testing Program & Preparation of Specimens.

### 3.4.1 Skid resistance tests:

#### 3.4.1.1 Sample preparation procedure:

##### 1-Flexible Pavement

1. A proper weight of aggregate gradation was heated to a temperature of 160 °c in the oven.
2. It was mixed with the proper weight of asphalt that was heated to a temperature of 135 °c in accordance with **ASTM Standard D 1559-79**.

3. After mixing thoroughly the material was cast in the specially made steel mold (150\*100\*75mm).
4. After casting the mixture was compacted by an hand compactor with 88 blows each face .

## **2- Rigid Pavement**

1. After that concrete was tilted and carried out on a wheel barrow to be cast in boards molds of size (150\*100\*75 mm).
2. It should be noted here that before casting the molds were cleaned and rigidly tightened then they were oiled lightly a light lubrication oil to prevent concrete sticking to the molds.
3. The molds were then fastened to the top of a vibrating table and casting was done in three equal layers.

### **3.4.1.2 British Pendulum Tester**

The procedure for determining the BPN of different surfaces follows as shown in Figure (3.7):

1. The tester was placed on the surface to be tested.
2. The base was levelled by the means of three levelling screws.
3. The head was raised so the pendulum arm was clear of the surface.
4. The head of the tester was lowered until it just touched the surface and was able to be rotated until it reached the end of contact.
5. The length of contact was compared with the length of the measuring device provided and the pendulum length was adjusted until the correct length was obtained.
6. The pendulum was raised and clamped horizontally in place.
7. The test area and slider were watered.
8. The pointer was moved to the stop.
9. The pendulum was released and caught on the return swing before it struck the surface again.

10. The value shown by the pointer was recorded.
11. This process was repeated four times and the results averaged.

### 3.4.1.3 Volumetric Method

The procedure for determining MTD of different surfaces follows as shown in Figure (3.8):

- 1) Procedure for this test consists of placing a known volume of material (V) on the pavement surface.
- 2) Spreading it using a circular motion until the sand is dispersed around the voids in the pavement surface.
- 3) The diameter of the area (D) covered with the sand is measured.
- 4) Then used to calculate the mean texture depth (MTD) of the pavement macrotexture.

The MTD is calculated from the test results using the following equation (**ASTM E965**):

$$\text{MTD} = 4V/\pi D^2 \quad (\text{mm}^3/\text{mm}^2) \quad \text{-----}3.4$$

### 3.4.1.4 International Friction Index

Methods are available for conversion of skid resistance parameters to the IFI .The IFI can be estimated (in Metric form, as outlined in **ASTM E 1960**) by following the steps below.

1. Measure Macro-texture—measure pavement macro-texture and compute MTD (**ASTM E 965**) (in millimeters).
2. Estimate the IFI Speed Number SP—Using the computed MTD, calculate SP (in km/hr) as follows

$$\text{SP} = -11.6 + 113.6 \times \text{MTD} \quad \text{-----}3.5$$

3. Calculate the IFI Friction Number F(60)—BPT results can be converted to F60 values through the relationship:

$$\text{F60} = 0.0436 + 0.0095 \times \text{BPN} \times \exp(-50/\text{SP}) \quad \text{-----}3.6$$



a. The tester was placed on the surface to be tested.



b. The length of contact was compared.



c. The pendulum was raised and clamped horizontally in place.

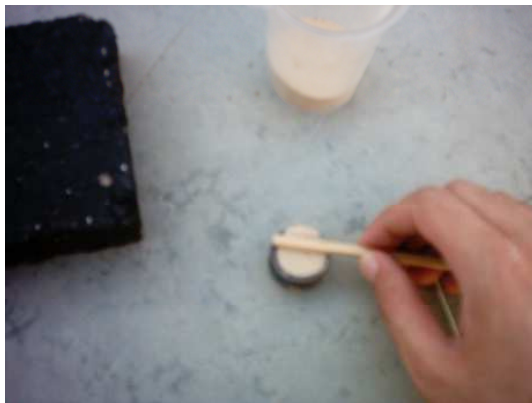


d. The pendulum was released.



e. The value shown by the pointer was recorded.

**Figure( 3.7) : Procedure for running a British Pendulum Tester to measure Microtexture using ASTM E-303.**



a. Measured amount of Sand in film container.



b. Pouring Sand onto pavement.



c. Sand poured onto pavement.



d. Spreading Sand with hockey puck.



e. Sand being spread to fill surface voids.



f. Measuring diameter of Sand circle.

**Figure( 3.8) : Procedure for running a sand patch test to measure macrotexture depth using ASTM E-965.**

### **3.4.2 Noise Level Measurements**

#### **3.4.2.1 Statistical Passby (SPB)**

The procedure for determining the Statistical Passby (SPB) can be summarized by.

- 1- The statistical pass-by (SPB) method consists of placing Sound level meter (SLM) at distance 7.5 m (25 ft) from the center of the vehicle lane at a height of 1.2 m (4 ft) above the pavement.
- 2- Determine sound pressure level for all 5 sec for hour period.
- 3- Determine average speed of vehicles passing through cross road for all 15 min.
- 4- Determined traffic volume and traffic density for all 15 min.
- 5- The data is used to compute a Statistical Passby Index.

#### **3.4.2.2 Controlled Passby (CPB)**

The procedure for determining the Controlled Passby (CPB) can be summarized by.

- 1- The Controlled Pass-by (CPB) method consists of placing Sound level meter (SLM) at distance 7.5 m (25 ft) from the center of the vehicle lane at a height of 1.2 m (4 ft) above the pavement.
- 2- Determine average sound pressure level for all speed (20, 30, 40, 50 and 60 Km/h).
- 3- Determine sound pressure level of streets upon compress on horn at speed 20 and 30 Km/h.
- 4- The data is used to compute a Statistical Passby Index.

# CHAPTER FOUR

## **Results of Experimental Work and Discussion**

# Chapter 4

## Results of Experimental Work and Discussion

In this chapter the results of all tests are presented and analyzed.

### 4.1 Marshall Test Results

In order to investigate the variation of Marshall test properties of asphalt concrete mixture, asphalt cement content (4.1, 4.7, 5.3 and 6.0) % is used for maximum aggregate size  $\frac{3}{4}$  inch; Intermediate gradation and maximum aggregate size (1,  $\frac{3}{4}$  and  $\frac{1}{2}$  inch) for asphalt cement content 4.7%; and Gradation limit (Fine gradation, Intermediate gradation and Coarse gradation) for asphalt cement content 4.7% and maximum aggregate size  $\frac{3}{4}$  inch. The filler used for all these mixtures is limestone dust. The different mixture variables used in this study are shown in table (4.1). The results are shown in Table (4.2).

Table (4-1) : Different Mixture Variables Used in the Work.

| Sample Variable        | aa 1            | aa 2 | aa 3 | aa 4 | aa 5 | aa 6 | bb 1                   | bb 2 | bb 3 | bb 4 | bb 5 | bb 6 | cc 1            | cc 2 | cc 3 | cc 4 | cc 5 | cc 6 |
|------------------------|-----------------|------|------|------|------|------|------------------------|------|------|------|------|------|-----------------|------|------|------|------|------|
| AC = 4.1 %             | *               |      |      |      |      |      | *                      |      |      |      |      |      | *               |      |      |      |      |      |
| AC = 4.7 %             |                 | *    |      |      | *    | *    |                        | *    |      |      | *    | *    |                 | *    |      |      | *    |      |
| AC = 5.3 %             |                 |      | *    |      |      |      |                        |      | *    |      |      |      |                 |      | *    | *    |      |      |
| AC = 6.0 %             |                 |      |      | *    |      |      |                        |      |      | *    |      |      |                 |      |      | *    |      |      |
| 1"                     | *               | *    | *    | *    | *    | *    |                        |      |      |      |      |      |                 |      |      |      |      |      |
| 3/4"                   |                 |      |      |      |      |      | *                      | *    | *    | *    | *    | *    |                 |      |      | *    | *    |      |
| 1/2"                   |                 |      |      |      |      |      |                        |      |      |      |      |      | *               | *    | *    | *    | *    | *    |
| Fine Gradation         |                 |      |      |      | *    |      |                        |      |      |      | *    |      |                 |      |      |      | *    |      |
| Intermediate Gradation | *               | *    | *    | *    |      |      | *                      | *    | *    | *    |      |      | *               | *    | *    | *    |      |      |
| Coarse Gradation       |                 |      |      |      |      | *    |                        |      |      |      |      | *    |                 |      |      |      |      | *    |
|                        | Asphalt Content |      |      |      |      |      | Aggregate Maximum Size |      |      |      |      |      | Gradation Limit |      |      |      |      |      |

**Table (4.2) :Effect of asphalt cement content, maximum aggregate size and Gradation Limit on Marshall criteria**

| Sample | Stability<br>(KN) | Flow<br>(mm) | Air voids<br>(%) | Bulk<br>Gravity<br>(gm/cm <sup>3</sup> ) | Gravity<br>(gm/cm <sup>3</sup> ) | Stiffness<br>KN/mm |
|--------|-------------------|--------------|------------------|------------------------------------------|----------------------------------|--------------------|
| aa2    | 10.70             | 2.4          | 5.27             | 2.351                                    | 2.482                            | 4.13               |
| cc2    | 9.90              | 3.5          | 4.53             | 2.34                                     | 2.451                            | 2.59               |
| bb1    | 9.98              | 2.5          | 4.95             | 2.377                                    | 2.501                            | 3.99               |
| bb2    | 10.10             | 2.9          | 4.72             | 2.391                                    | 2.509                            | 3.48               |
| bb3    | 10.50             | 3.1          | 3.8              | 2.405                                    | 2.5                              | 3.39               |
| bb4    | 9.45              | 3.5          | 3.15             | 2.432                                    | 2.511                            | 2.70               |
| bb5    | 10.90             | 3.5          | 4.82             | 2.373                                    | 2.493                            | 3.11               |
| bb6    | 9.50              | 3.7          | 4                | 2.331                                    | 2.428                            | 2.57               |

## **4.2 Concrete mixture performance and related with friction number (F60).**

The compressive strength of concrete is perhaps the most comprehensive measure of concrete quality while tensile strength is a property directly related to the performance of PCC pavements. The PCC tensile characteristics directly affect the initiation of transverse cracking and corner breaks. The PCC elastic modulus is an important variable in pavement design as it controls the overall slab deflection from traffic loading and the slab curling stresses.

The Table (4.3) shows the comparison between Compressive strength, Tensile strength, and Modulus of Elasticity strength with F60.

This, the following notes from this Table are as follows:

- 1) Using the mix ratio 1:3:6 increases F60 but decreases durable concrete while using the mix ratio 1:1.5:3 decreases F60 but increases durable concrete.
- 2) Using water to cement ratio 0.65 decreases all from F60 and durable concrete while using w/c ratio 0.45 increases all from F60 and durable concrete.
- 3) Using maximizes aggregate size 1" increases all from durable and F60 while using maximize aggregate size ½" noted decreases all from F60 and durable.

### **4.3 Skid Resistance Results:-**

The results of this test shows the effect of various variables for rigid pavement (aggregate maximum size, water to cement ratio, mix ratio, finishing and pavement surface condition) and for flexible pavement the variables aggregate maximum size, asphalt content, and pavement surface condition.

#### **4.3.1 Rigid Pavement**

##### **Properties of Used Samples**

The different mixture variables used in Rigid Pavement are shown in Table (4.4). The results of skid resistance for Rigid Pavement variability are shown in Table (A.1) Appendix A.

**Table (4-3) :The relationship between Compressive strength, Tensile strength and Modulus of Elasticity strength and F60.**

| AGGREGATE<br>MAXIMUM<br>SIZE<br>(INCH) | WATER<br>TO<br>CEMENT<br>RATIO | CEMENT<br>TO SAND<br>TO<br>GRAVEL<br>RATIO | F60 | COMPRESSIVE<br>STRENGTH(MPA)<br>FOR 28 DAY | TENSILE<br>STRENGTH(MPA)<br>FOR 28 DAY | MODULUS OF<br>ELASISTY(GPA)<br>FOR 28 DAY |
|----------------------------------------|--------------------------------|--------------------------------------------|-----|--------------------------------------------|----------------------------------------|-------------------------------------------|
| 1                                      | 0.65                           | 1:1.5:3                                    | 49  | 26.00                                      | 2.62                                   | 30.59                                     |
| 1                                      | 0.65                           | 1:2:4                                      | 53  | 24.02                                      | 4.27                                   | 29.43                                     |
| 1                                      | 0.65                           | 1:3:6                                      | 63  | 18.28                                      | 4.49                                   | 30.11                                     |
| 1                                      | 0.55                           | 1:1.5:3                                    | 68  | 28.71                                      | 5.52                                   | 30.75                                     |
| 1                                      | 0.55                           | 1:2:4                                      | 69  | 30.49                                      | 3.39                                   | 31.08                                     |
| 1                                      | 0.55                           | 1:3:6                                      | 72  | 19.98                                      | 2.75                                   | 33.13                                     |
| 1                                      | 0.45                           | 1:1.5:3                                    | 65  | 33.11                                      | 4.99                                   | 33.04                                     |
| 1                                      | 0.45                           | 1:2:4                                      | 63  | 31.49                                      | 5.25                                   | 31.97                                     |
| 1                                      | 0.45                           | 1:3:6                                      | 74  | 20.52                                      | 5.01                                   | 28.57                                     |
| 0.75                                   | 0.65                           | 1:1.5:3                                    | 47  | 25.00                                      | 3.30                                   | 30.23                                     |
| 0.75                                   | 0.65                           | 1:2:4                                      | 42  | 23.25                                      | 6.46                                   | 29.20                                     |
| 0.75                                   | 0.65                           | 1:3:6                                      | 58  | 18.66                                      | 5.52                                   | 30.34                                     |
| 0.75                                   | 0.55                           | 1:1.5:3                                    | 54  | 28.35                                      | 4.20                                   | 30.97                                     |
| 0.75                                   | 0.55                           | 1:2:4                                      | 52  | 28.07                                      | 5.27                                   | 32.09                                     |
| 0.75                                   | 0.55                           | 1:3:6                                      | 55  | 20.66                                      | 5.52                                   | 28.09                                     |
| 0.75                                   | 0.45                           | 1:1.5:3                                    | 44  | 33.57                                      | 3.47                                   | 33.06                                     |
| 0.75                                   | 0.45                           | 1:2:4                                      | 64  | 32.72                                      | 3.18                                   | 33.37                                     |
| 0.75                                   | 0.45                           | 1:3:6                                      | 66  | 22.82                                      | 4.44                                   | 29.14                                     |
| 0.5                                    | 0.65                           | 1:1.5:3                                    | 30  | 22.00                                      | 5.81                                   | 28.12                                     |
| 0.5                                    | 0.65                           | 1:2:4                                      | 41  | 21.37                                      | 5.81                                   | 27.77                                     |
| 0.5                                    | 0.65                           | 1:3:6                                      | 48  | 19.38                                      | 3.34                                   | 28.06                                     |
| 0.5                                    | 0.55                           | 1:1.5:3                                    | 47  | 26.39                                      | 6.48                                   | 32.22                                     |
| 0.5                                    | 0.55                           | 1:2:4                                      | 47  | 23.63                                      | 4.27                                   | 29.99                                     |
| 0.5                                    | 0.55                           | 1:3:6                                      | 66  | 21.76                                      | 5.45                                   | 28.37                                     |
| 0.5                                    | 0.45                           | 1:1.5:3                                    | 36  | 34.23                                      | 7.15                                   | 35.43                                     |
| 0.5                                    | 0.45                           | 1:2:4                                      | 60  | 31.37                                      | 7.15                                   | 35.67                                     |
| 0.5                                    | 0.45                           | 1:3:6                                      | 68  | 25.70                                      | 4.11                                   | 36.32                                     |

Table (4-4) : Different Mixture Variables Used in the Work.

| Sample<br>Variable        | A1 | A2 | A3 | A4 | A5 | A6 | B1 | B2 | B3 | B4 | B5 | B6 | C1 | C2 | C3 | C4 | C5 | C6 |
|---------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1"                        | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  | *  |
| ½"                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| ¾"                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Aggregate<br>Maximum Size |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 0.65                      | *  | *  | *  | *  | *  | *  |    |    |    |    |    |    |    |    |    |    |    |    |
| 0.55                      |    |    |    |    |    |    | *  | *  | *  | *  | *  | *  |    |    |    |    |    |    |
| 0.45                      |    |    |    |    |    |    |    |    |    |    |    |    | *  | *  | *  | *  | *  | *  |
| water to cement<br>ratio  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 1:1.5:3                   | *  | *  |    |    |    |    | *  | *  |    |    |    |    | *  | *  |    |    |    |    |
| 1:2:4                     |    |    | *  | *  |    |    |    |    | *  | *  |    |    |    |    | *  | *  | *  | *  |
| 1:3:6                     |    |    |    |    | *  | *  |    |    |    |    |    |    |    |    |    |    |    |    |
| Mix Ratio                 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Smooth                    | *  |    | *  |    | *  |    | *  |    | *  |    | *  |    | *  |    | *  |    | *  | *  |
| Rough                     |    | *  |    | *  |    | *  |    | *  |    | *  |    | *  |    | *  |    | *  |    | *  |
| Finishing of<br>Surface   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

Table (4-4) : Continued different Mixture Variables Used in the Work.

| Sample<br>Variable        | D1 | D2 | D3 | D4 | D5 | D6 | E1                       | E2 | E3 | E4 | E5 | E6 | F1        | F2 | F3 | F4                      | F5 | F6 |
|---------------------------|----|----|----|----|----|----|--------------------------|----|----|----|----|----|-----------|----|----|-------------------------|----|----|
| 1"                        |    |    |    |    |    |    |                          |    |    |    |    |    |           |    |    |                         |    |    |
| 1/2"                      | *  | *  | *  | *  | *  | *  | *                        | *  | *  | *  | *  | *  | *         | *  | *  | *                       | *  | *  |
| 3/4"                      |    |    |    |    |    |    |                          |    |    |    |    |    |           |    |    |                         |    |    |
| 0.65                      | *  | *  | *  | *  | *  | *  |                          |    |    |    |    |    |           |    |    |                         |    | *  |
| 0.55                      |    |    |    |    |    |    | *                        | *  | *  | *  | *  | *  |           |    |    |                         |    |    |
| 0.45                      |    |    |    |    |    |    |                          |    |    |    |    |    | *         | *  | *  | *                       | *  | *  |
| 1:1.5:3                   | *  | *  |    |    |    |    | *                        | *  |    |    |    |    | *         | *  |    |                         |    |    |
| 1:2:4                     |    |    | *  | *  |    |    |                          |    | *  | *  |    |    |           |    | *  | *                       |    |    |
| 1:3:6                     |    |    |    |    | *  | *  |                          |    |    |    | *  | *  |           |    |    |                         | *  | *  |
| Smooth                    | *  |    | *  |    | *  |    | *                        |    | *  |    | *  |    | *         |    | *  |                         | *  |    |
| Rough                     |    | *  |    | *  |    | *  |                          | *  |    | *  |    | *  |           | *  |    | *                       |    | *  |
| Aggregate<br>Maximum Size |    |    |    |    |    |    | water to cement<br>ratio |    |    |    |    |    | Mix Ratio |    |    | Finishing<br>of Surface |    |    |

Table (4-4) : Continued different Mixture Variables Used in the Work.

| Sample<br>Variable        | G<br>1 | G<br>2 | G<br>3 | G<br>4 | G<br>5 | G<br>6 | H<br>1 | H<br>2 | H<br>3 | H<br>4 | H<br>5 | H<br>6 | K<br>1 | K<br>2 | K<br>3 | K<br>4 | K<br>5 | K<br>6 |
|---------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1"                        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 1/2"                      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 3/4"                      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      | *      |
| 0.65                      | *      | *      | *      | *      | *      | *      |        |        |        |        |        |        |        |        |        |        |        |        |
| 0.55                      |        |        |        |        |        |        | *      | *      | *      | *      | *      | *      |        |        |        |        |        |        |
| 0.45                      |        |        |        |        |        |        |        |        |        |        |        |        | *      | *      | *      | *      | *      | *      |
| 1:1.5:3                   | *      | *      |        |        |        |        | *      | *      | *      |        |        |        | *      | *      |        |        |        |        |
| 1:2:4                     |        | *      | *      | *      |        |        |        |        | *      | *      |        |        |        |        | *      | *      |        |        |
| 1:3:6                     |        |        |        |        | *      | *      |        |        |        |        | *      | *      |        |        |        |        | *      | *      |
| Smooth                    | *      |        | *      |        | *      |        | *      |        | *      |        | *      |        | *      |        | *      |        | *      |        |
| Rough                     |        | *      |        | *      |        | *      |        | *      |        | *      |        | *      |        | *      |        | *      |        | *      |
| Aggregate<br>Maximum Size |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| water to cement<br>ratio  |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Mix Ratio                 |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Finishing<br>of Surface   |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |

#### 4.3.1.1 Effect of Aggregate Maximum Size

To investigate the effect of aggregate maximum size on skid resistance, three different sizes are used (1",  $\frac{3}{4}$ " and  $\frac{1}{2}$ " inch), which represent the most frequently used in the concrete paving.

Figures (4.1) to (4.3) show the effect of aggregate maximum size on skid resistance.

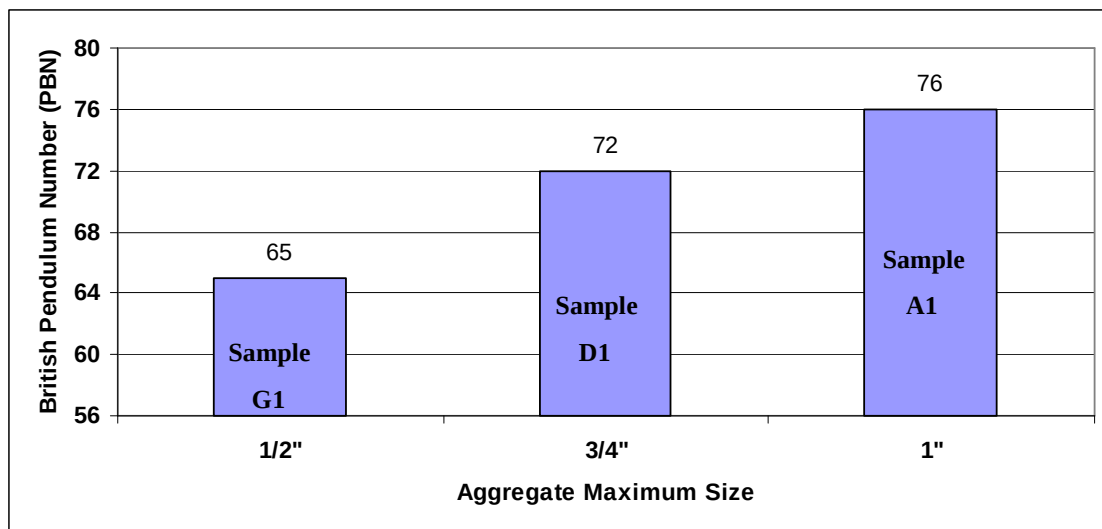


**Figure (4.1) : Influence of (aggregate maximum size) on (PBN).**

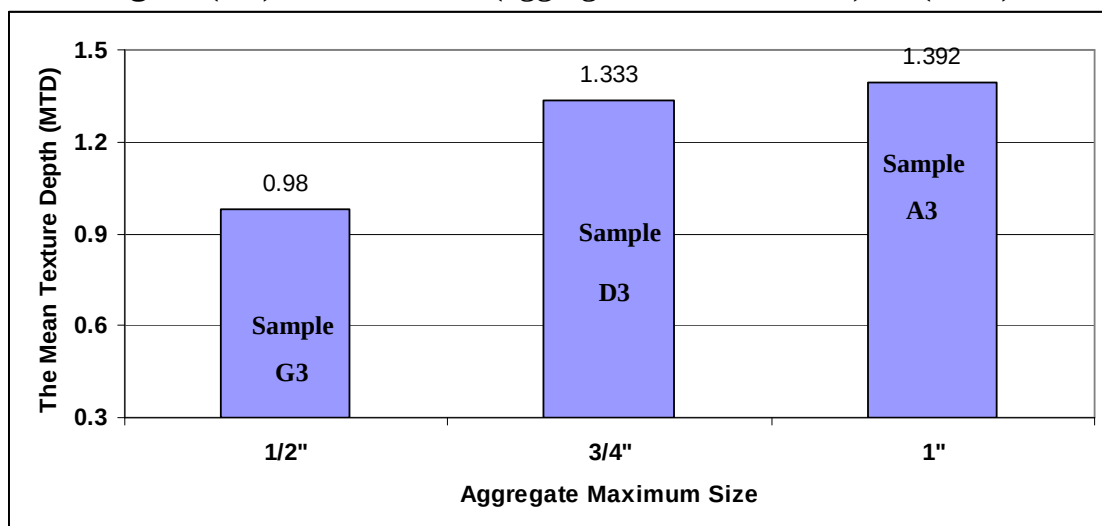


**Figure (4.2) : Influence of (aggregate maximum size) on (MTD).**

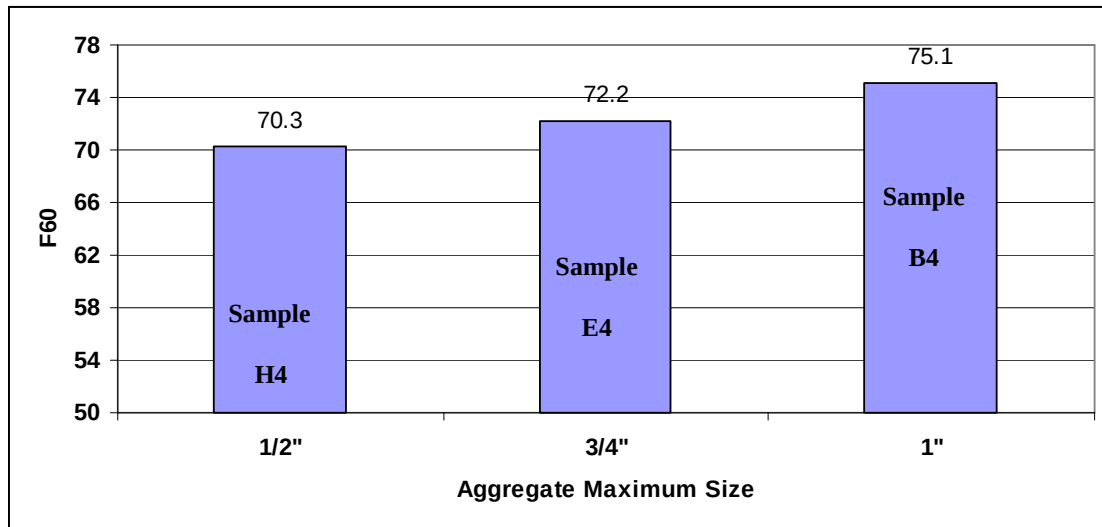


**Figure (4.3) : Influence of (aggregate maximum size) on F60.**

It is clear from Figures (4.1, 4.2 and 4.3) that the aggregate maximum size greatly influences the British Pendulum Number (BPN) which increases with the increase of aggregate maximum size. On the other hand, the Mean Texture Depth (MTD) is slightly increased with the increase of aggregate maximum size.

This is because the larger the size of aggregate incorporated into surface pavement may increase the contact of small asperities in the aggregate surface at the pavement-to-tire interface.

#### 4.3.1.2 Water to Cement Ratio (W/C)

In order to evaluate the effect of water to cement ratio on skid resistance, three different ratios are used (0.65, 0.55 and 0.45).

Figures (4.4) to (4.6) show the effect of water to cement ratio on skid resistance.

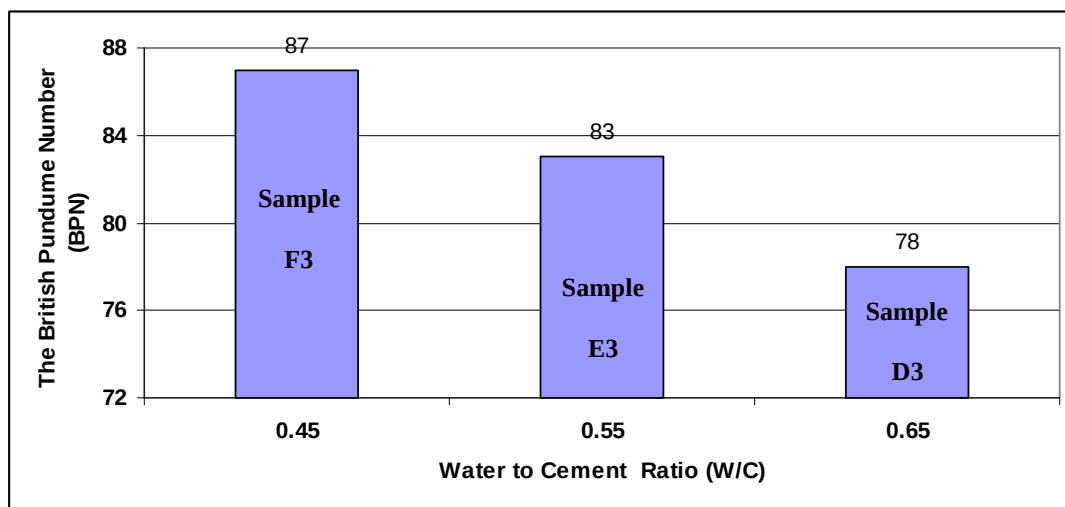


**Figure (4.4) : Influence of (water to cement ratio (W/C) on British Pendulum Number PBN.**

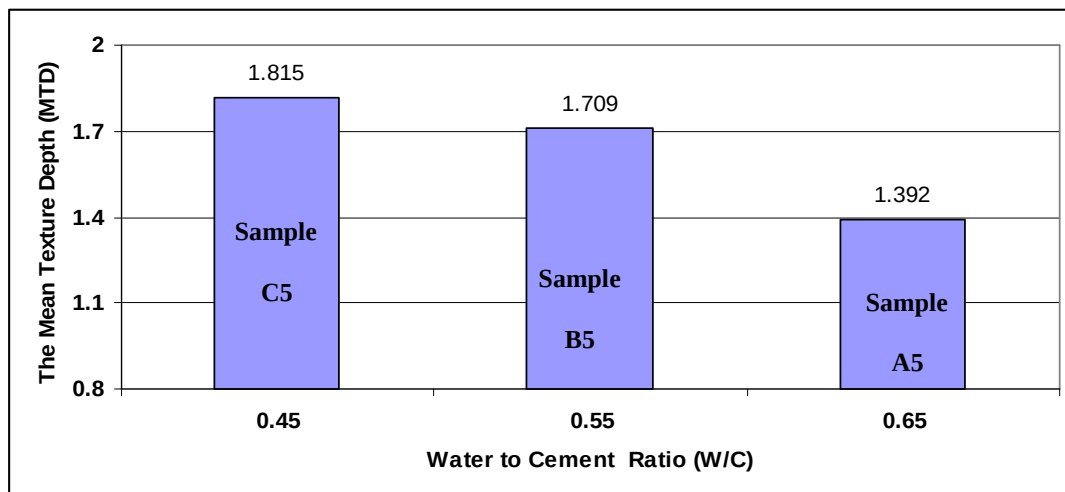


**Figure (4.5) : Influence of (water to cement ratio (W/C) On Macrotexture Depth(MTD).**

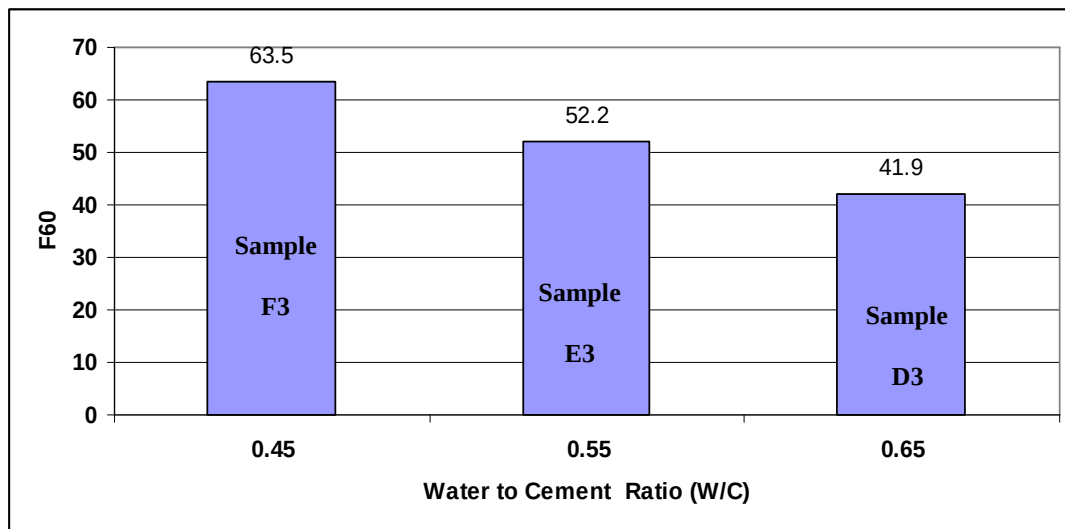


**Figure (4.6) : Influence of (water to cement ratio (W/C) on F60.**

Figures (4.4, to 4.6) indicate that the Water to Cement (W/C) ratio influences the British Pendulum Number (BPN) which decreases with the increase of W/C ratio. On the other hand, the Mean Texture Depth (MTD) is decreased with the increase of W/C ratio.

This is because increasing the proportion of water leading to increased bleeding and therefore the rise of water to the surface which in turn leads to making the surface smoother.

#### **4.3.1.3 Effect of Finishing**

Concrete finishing is a critical step in the paving process. Two different finishing (smooth and rough) have been selected to study the effect of test finishing on skid resistance.

Figures (4.7) to (4.9) show the effect of Finishing on skid resistance.

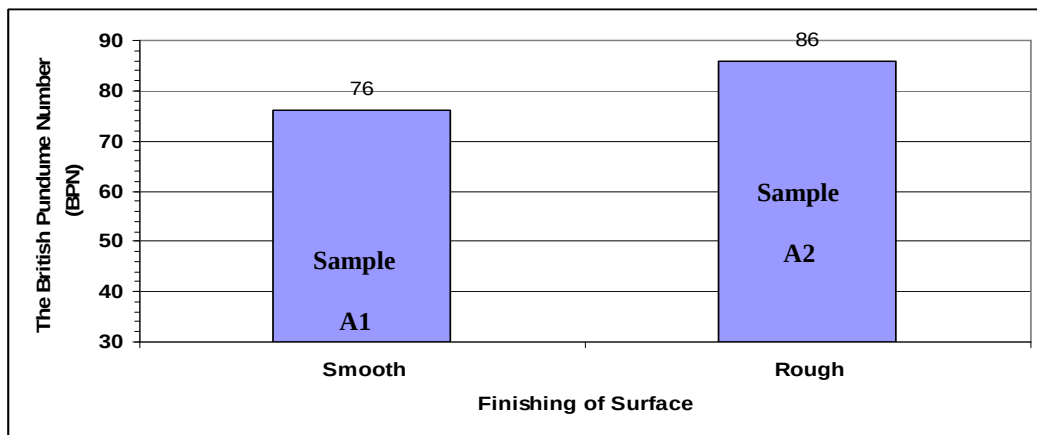


**Figure (4.7) : Influence of (Finishing) on British Pendulum Number (BPN).**

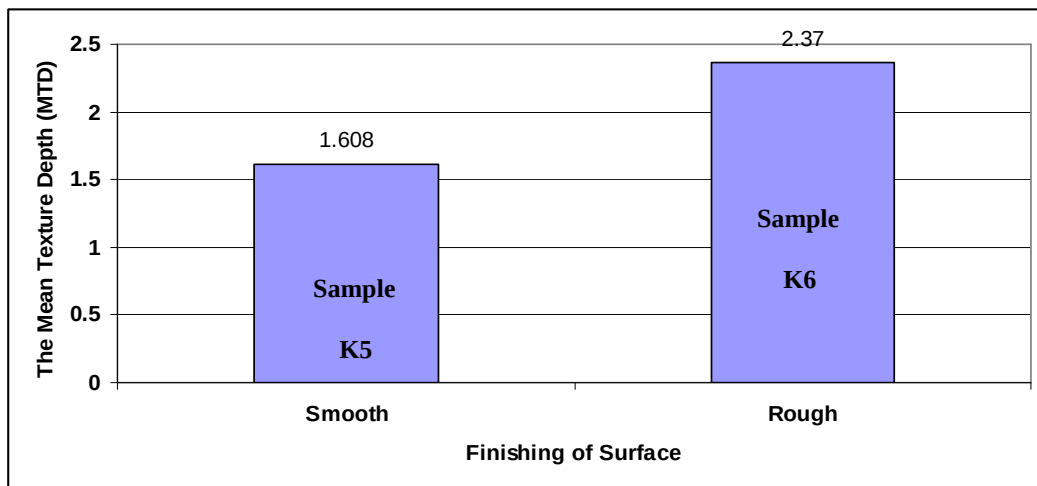


**Figure (4.8) : Influence of (Finishing) on Macrotexture Depth(MTD).**

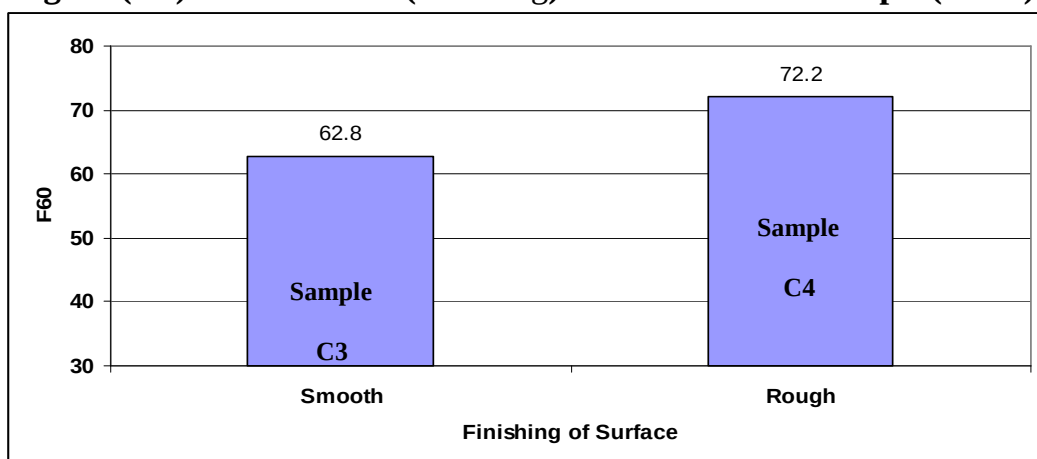


**Figure (4.9) : Influence of (Finishing) on F60.**

Both MTD and BPN are influenced by finishing; they are greatly increased by rough finishing than smooth finishing.

The Rough offered better skid resistance as compared to Smooth, as indicated by the higher pendulum measurements. Moreover they provided more resistance against the effects of water with a lower decrease in the pendulum measurements as compared to Smooth. The texture created by rough provided a channel for water to be drained, thereby maintaining the contact between the rubber slider and the test specimen (**Yang Pin Kelvin LEE, 2003**).

#### 4.3.1.4 Effect of Surface Conditions

Two different variables (dry and wet) are used for surface conditions. Figures (4.10) and (4.11) show the effect of surface condition on skid resistance.

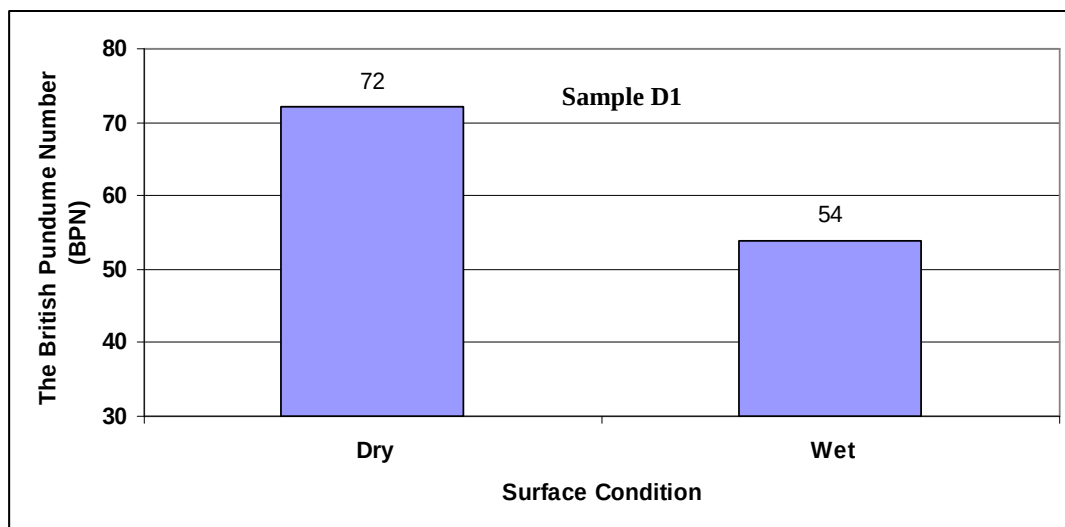


**Figure (4.10) : Influence of (surface condition) on British Pendulum Number (BPN).**

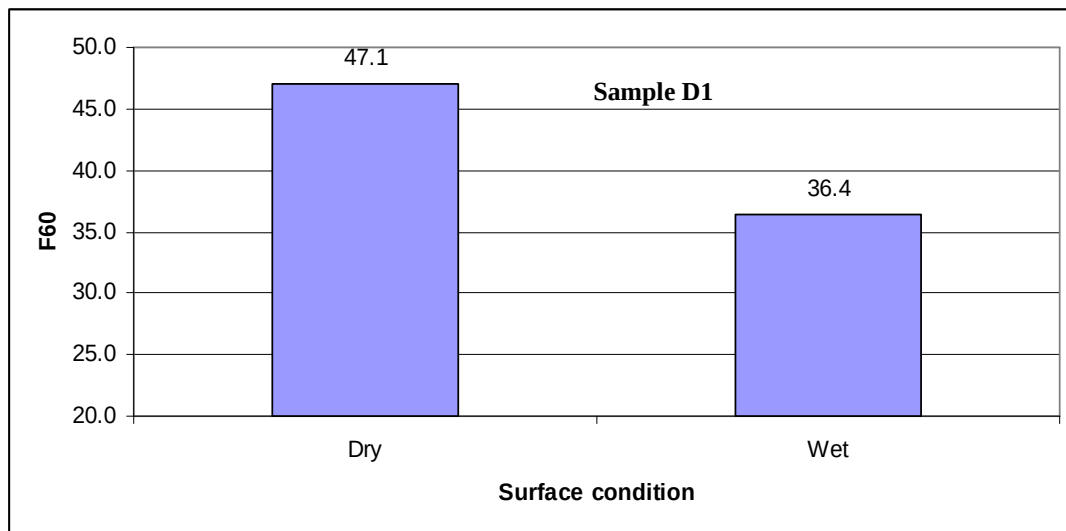


**Figure (4.11) : Influence of (surface condition) on F60.**

The value of BPN obtained from dry surface is greater than that obtained from wet surface. The water greatly decreases contact between surface and tyre; hence, the skid resistance is decreased.

But for all highway design standards, wet surface condition must be taken into consideration because dry pavements are believed to provide sufficient skid resistance for stopping vehicles.

#### **4.3.1.5 Effect of Mix Ratio.**

To investigate the effect of mix ratio on skid resistance, three different mixer ratio are used (1:1.5:3, 1:2:4 and 1:3:6).

Figures (4.12, 4.13 and 4.14) show the effect of mix ratio on skid resistance.

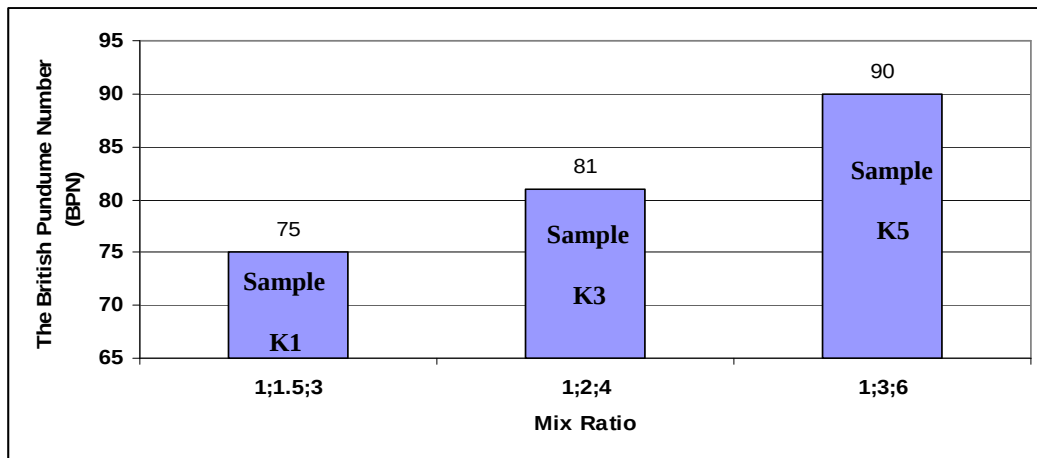


**Figure (4.12) : Influence of (mix ratio) on British Pendulum Number (BPN).**

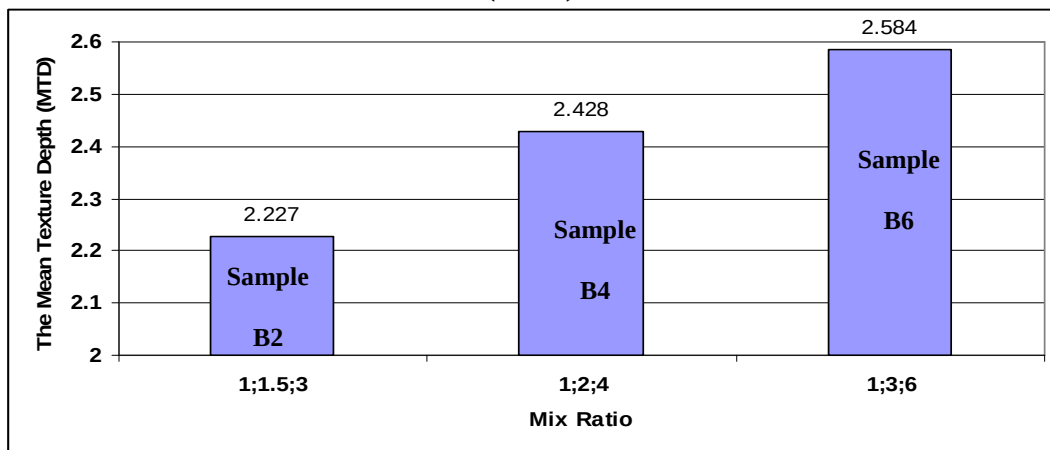


**Figure (4.13) : Influence of (mix ratio) on Macrotexture Depth(MTD).**

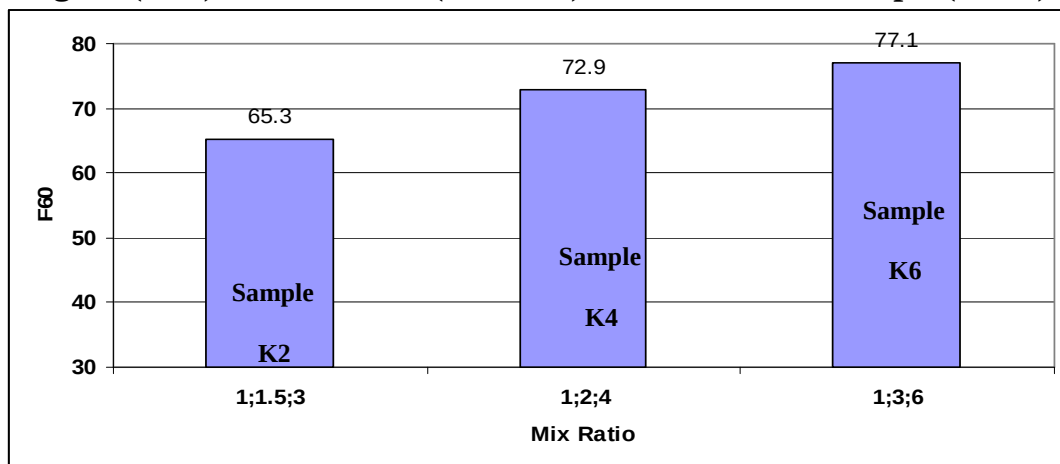


**Figure (4.14) : Influence of (mix ratio) on F60.**

It can be seen from Figures (4.12, 4.13 and 4.14) that the Mix Ratio greatly influences the British Pendulum Number (BPN) which increases with the increase of Mix Ratio. On the other hand, the Mean Texture Depth (MTD) is increased with the increase of Mix Ratio, because increasing the aggregate quantity in the mixture increases surface roughness.

### 4.3.2 Flexible Pavement.

#### Properties of Used Samples

The results of skid resistances for Flexible pavements are shown in Tables (4.5) and (4.6).

**Table (4.5) : Effect of Asphalt Cement Content and Maximum Aggregate Size on Friction Pavement.**

| AGG MAX.<br>SIZE (INCH) | AC<br>(%) | BPN | MTD<br>(MM) | F60   |
|-------------------------|-----------|-----|-------------|-------|
| 1"                      | 4.1       | 87  | 0.874       | 51.09 |
|                         | 4.7       | 84  | 0.830       | 47.95 |
|                         | 5.3       | 81  | 0.783       | 44.68 |
|                         | 6.0       | 79  | 0.745       | 42.21 |
| ¾"                      | 4.1       | 82  | 0.821       | 46.59 |
|                         | 4.7       | 77  | 0.776       | 42.43 |
|                         | 5.3       | 73  | 0.731       | 38.80 |
|                         | 6.0       | 70  | 0.706       | 36.44 |
| ½"                      | 4.1       | 74  | 0.701       | 38.07 |
|                         | 4.7       | 72  | 0.660       | 35.44 |
|                         | 5.3       | 68  | 0.643       | 32.99 |
|                         | 6.0       | 65  | 0.600       | 29.87 |

**Table (4.6) : Effect of Maximum Aggregate Size and Gradation Limit on Friction Pavement.**

| AGG MAX.<br>SIZE<br>(INCH) | GRADATION LIMIT        | BPN | MTD<br>(MM) | F60   |
|----------------------------|------------------------|-----|-------------|-------|
| 1"                         | Fine Gradation         | 78  | 0.698       | 39.76 |
|                            | Intermediate Gradation | 82  | 0.830       | 46.91 |
|                            | Coarse Gradation       | 87  | 0.876       | 51.16 |
| ¾"                         | Fine Gradation         | 71  | 0.663       | 35.13 |
|                            | Intermediate Gradation | 77  | 0.776       | 42.43 |
|                            | Coarse Gradation       | 82  | 0.833       | 47.02 |
| ½"                         | Fine Gradation         | 66  | 0.546       | 27.62 |
|                            | Intermediat Gradation  | 72  | 0.660       | 35.44 |
|                            | Coarse Gradation       | 80  | 0.802       | 44.88 |

**4.3.2.1 Effect of Asphalt Content:**

In order to explain the effect of asphalt cement content on skid resistance, different percentages of asphalt cement content are used (4.1, 4.7, 5.3 and 6.0) % by Wight of total mix. These ratios within the limits allowed Marshall Test to design asphalt mixture.

Figures (4.15) to (4.17) show the effect of asphalt cement content on skid resistance.

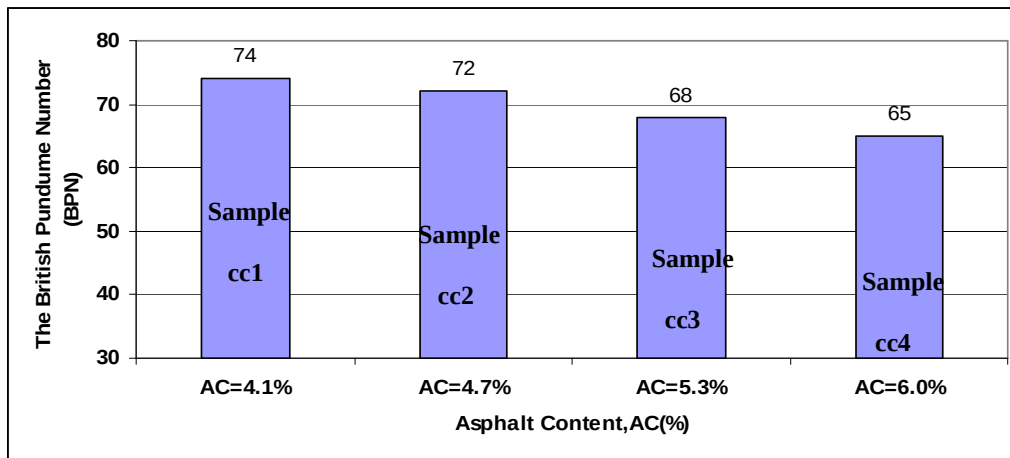


**Figure (4.15) : Influence of (asphalt cement content) ratio on BPN.**

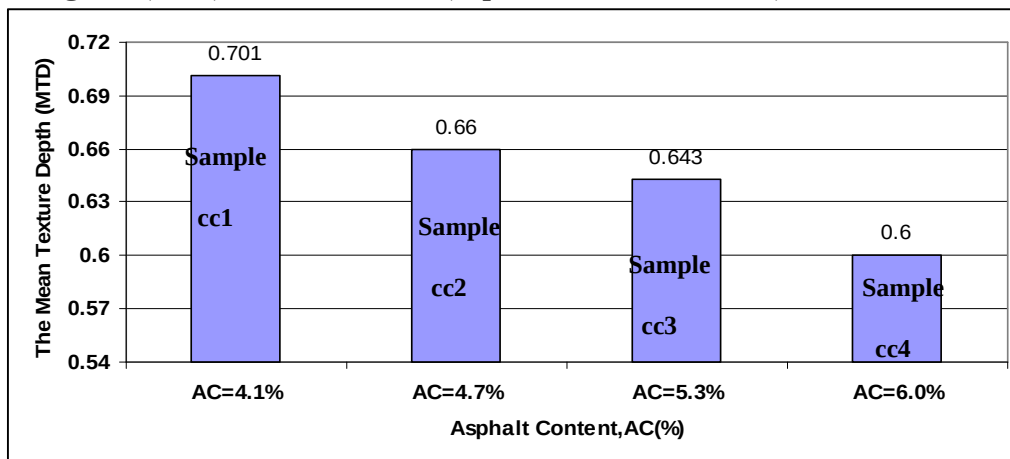


**Figure (4.16) : Influence of (asphalt cement content) ratio on MTD.**

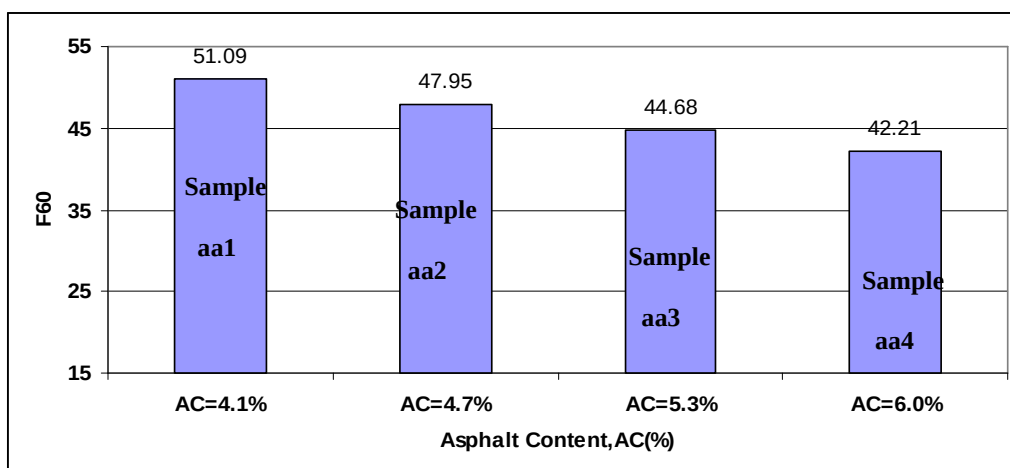


**Figure (4.17) :Influence of (asphalt cement content) ratio on F60.**

It is clear from Figures (4.15, 4.16 and 4.17) that the asphalt cement content greatly influences the British Pendulum Number (BPN) which decreases with the increase of asphalt cement content. On the other hand, the Mean Texture Depth (MTD) is decreased with the increase of asphalt cement content.

Increasing asphalt cement content of mixture may occur bleed because the depressions of the texture being filled with asphalt, which prevents vehicle tyres from adequately contacting the aggregate in the pavement surface.

#### 4.3.2.2 Effect of Aggregate Maximum Size

To investigate the effect of aggregate maximum size on skid resistance, three different size are used (25, 19 and 12.5mm) gradation of Nibae crushed aggregate. The results for the effect of aggregate maximum size are shown in Tables (4.1) and (4.2).

Figures (4.18, 4.19 and 4.20) show the effect of aggregate maximum size on skid resistance.

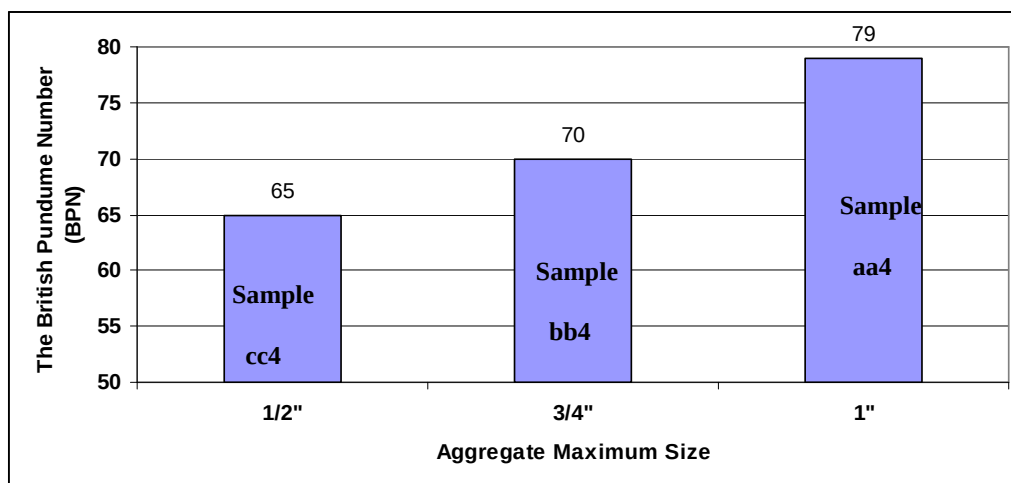


**Figure (4.18) : Influence of (aggregate maximum size) ratio on BPN.**

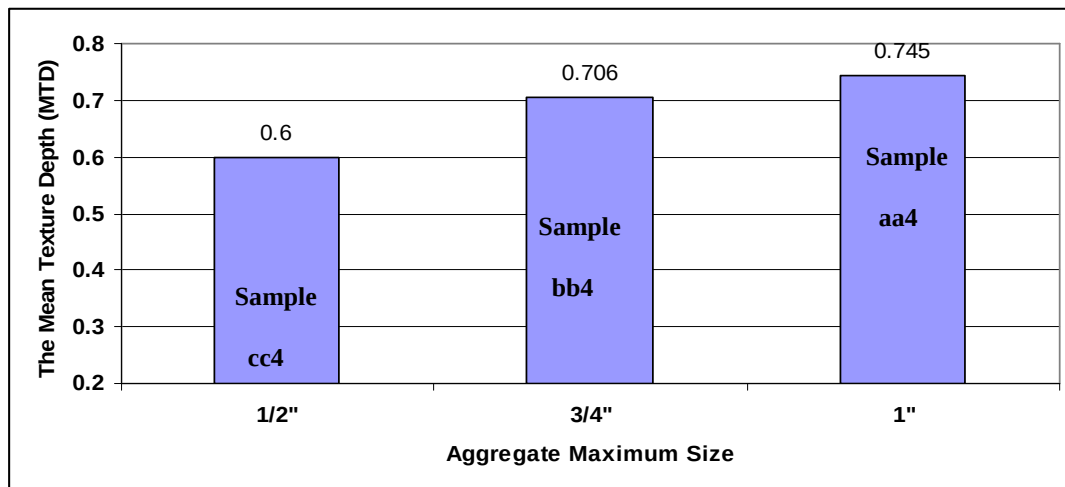


**Figure (4.19) : Influence of (aggregate maximum size) ratio on MTD.**

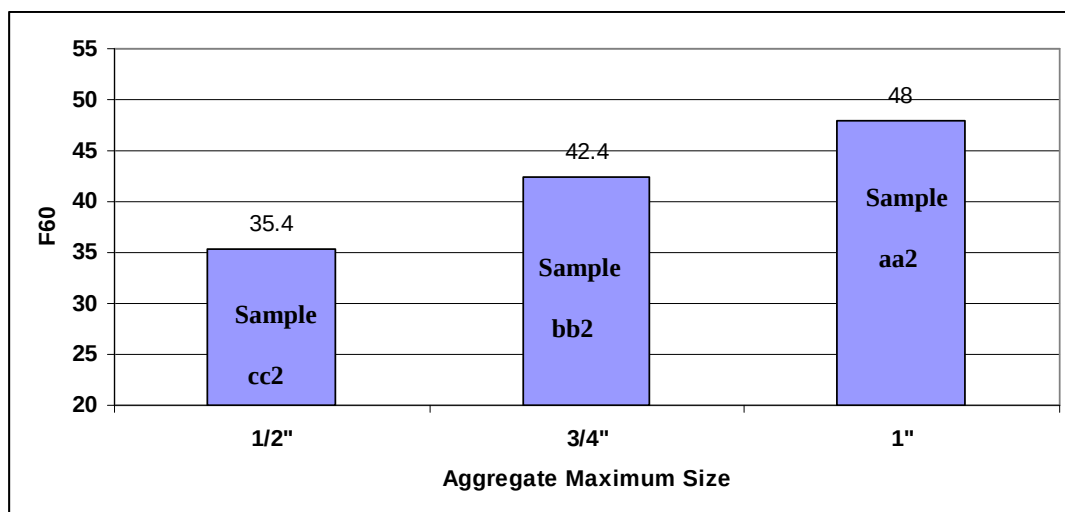


**Figure (4.20) : Influence of (aggregate maximum size) ratio on F60.**

It can be seen from Figures (4.18, 4.19 and 4.20) that the aggregate maximum size greatly influences the British Pendulum Number (BPN) which increases with the increase of aggregate maximum size. On the other hand, the Mean Texture Depth (MTD) is increased with the increase of aggregate maximum size.

This is because the larger the size of aggregate incorporated into surface pavement may increase the contact of small asperities in the aggregate surface at the pavement-to-tire interface.

#### 4.3.2.3 Influence of Gradation Limit on Friction

The effects of Gradation Limit on skid resistance are shown in Figures (4.21, 4.22 and 4.23).

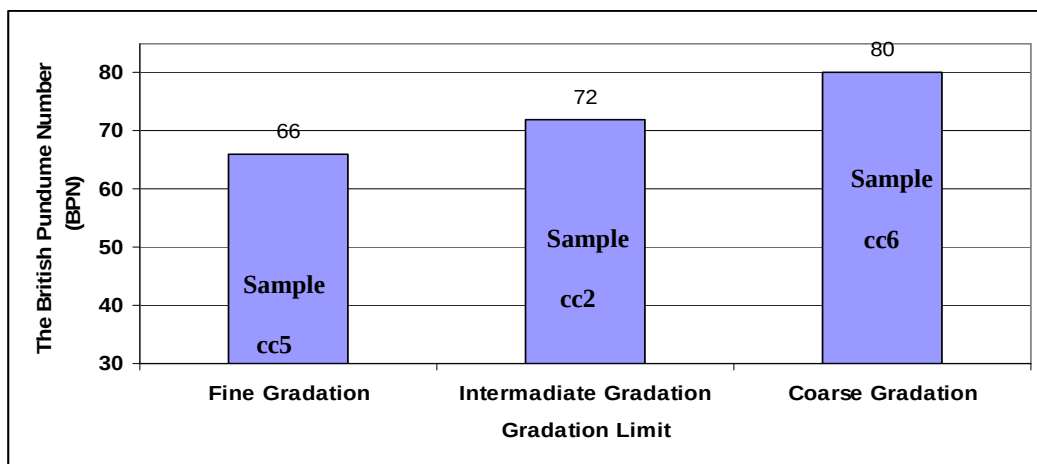


**Figure (4.21) : Influence of (gradation limit) ratio on BPN.**

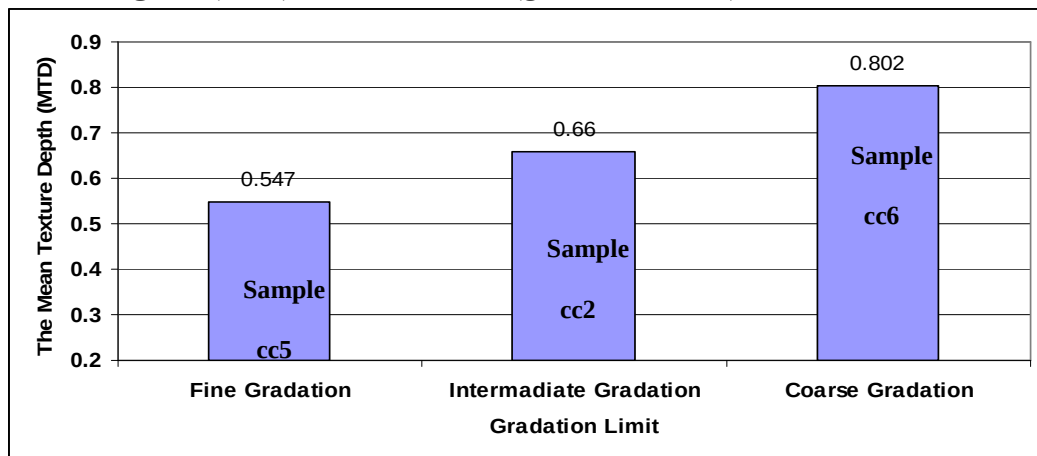


**Figure (4.22) : Influence of (gradation limit) ratio on MTD.**

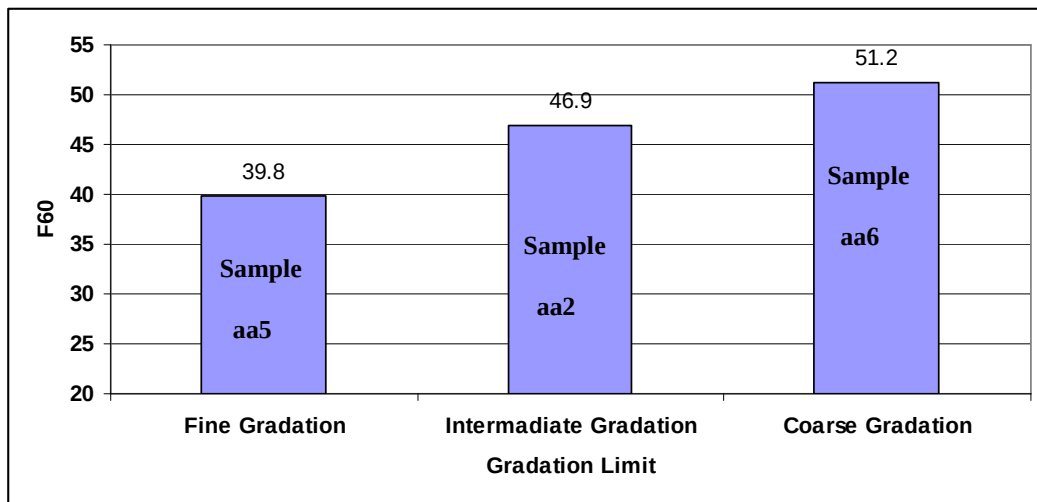


**Figure (4.23) : Influence of (gradation limit) ratio on F60.**

From test results, the gradation limit influence on British Pendulum Number (BPN) and Mean Texture Depth (MTD) increases with the aggregate Coarse Gradation increase.

The coarse graded mixture (lower gradation limit) of asphalt concrete mixtures has more resistance to skidding because the mix has more roughness for having greater percentage of aggregate.

#### **4.3.2.4 Effect of Surface Conditions**

Two different variables (dry and wet) are used for surface conditions. Figures (4.24) and (4.25) show the effect of surface condition on skid resistance.

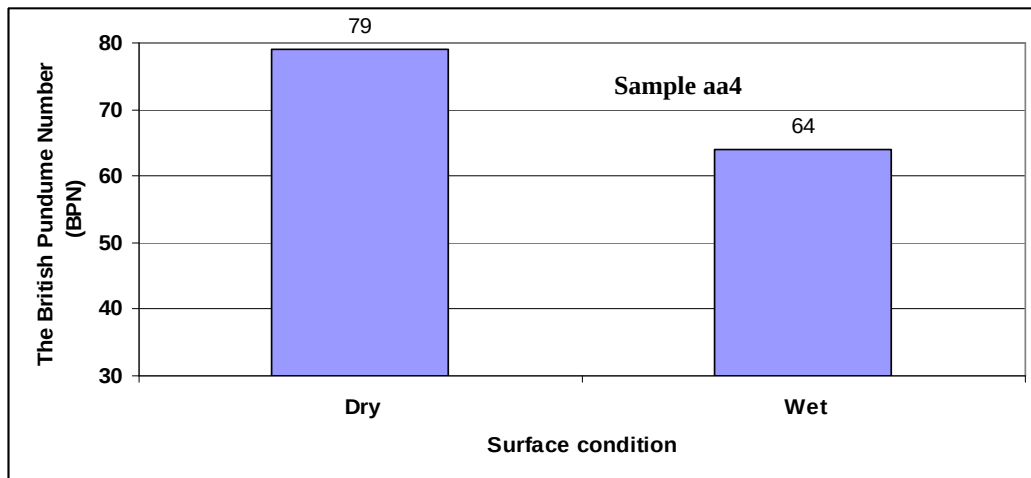


**Figure (4.24) : Influence of (surface condition) on British Pendulum Number (BPN).**

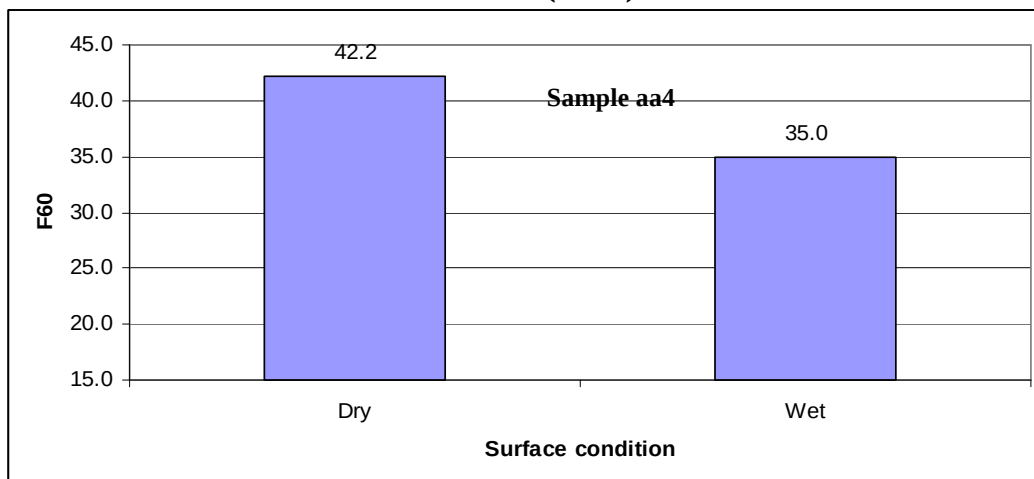


**Figure (4.25) :Influence of (surface condition) on F60.**

The value of BPN obtained from dry surface is greater than that obtained from wet surface. The water greatly decreases contact between surface and tyre; hence, the skid resistance is decreased.

But for all highway design standards, wet surface condition must be taken into consideration because dry pavements are believed to provide sufficient skid resistance for stopping vehicles.

## 4.4 Prediction of Skid Resistance for Flexible and Rigid Pavement

The first step in the development of the statistical analysis was selection of the form of the relationship between the dependent and the independent variables:

The dependent variable is: F60.

The independent variables are:

- Water/Cement ratio, Aggregate Maximum Size, Mix ratio, and Finishing for Rigid pavement.
- Aggregate maximum mineral size, Asphalt Content and Gradation Limit for Flexible pavement.

### 4.4.1 Selecting Sample Size.

In statistical consulting the first question frequently asked is “how large should the sample size be ?” (**Hogg and Tanis, 1988**).

Kennedy and Neville (1986) stated that, there is no direct answer to this question. They mentioned that the larger the sample size the greater the cost of testing but on the other hand the greater the amount of information derived.

#### Sample Size for the Developed Models

The following formula is used to determine the required sample size. This formula can be found in (**Kennedy and Neville,1986**).

$$E = V * t / (n)^{0.5}$$

Where,

$E$  = error of the mean

$t$  = t-statistics, and

$n$  = sample size.

$V$  = coefficient of variation.

### **Rigid Pavement**

#### **F60**

$n = 54$

For; confidence level =95%, then  $t=1.96$

$V = 0.19$

$E = (0.19 \times 1.96) / 54^{0.5}$

$E = 0.051$

Then, the sample size is accepted with this percent of error.

### **Flexible Pavement**

#### **F60**

$n = 18$

For; confidence level =95%, then  $t=1.96$

$V = 0.17$

$E = (0.17 \times 1.96) / 18^{0.5}$

$E = 0.079$

Then, the sample size is accepted with this percent of error.

## 4.4.2 Correlation Matrix.

### 4.4.2.1 Correlation Matrix of Rigid pavement.

Correlation Matrix of Rigid pavement for MTD, PBN and F60 are shown in Tables (4.7) to (4.9) respectively.

**Table (4.7) :Correlation Matrix of Rigid pavement for MTD Model.**

| Stat.<br>multiple<br>regress. | Correlations, N=54 (Casewise deletion of missing data)(MTD. Sta)<br>, Rigid pavement |             |             |             |             |
|-------------------------------|--------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|
| variable                      | MAX                                                                                  | WC          | CSG         | F           | MTD         |
| MAX                           | <b>1.00</b>                                                                          | 0.04        | -0.03       | -0.06       | 0.10        |
| WC                            | 0.04                                                                                 | <b>1.00</b> | -0.03       | 0.02        | -0.25       |
| CSG                           | -0.03                                                                                | -0.03       | <b>1.00</b> | 0.01        | 0.34        |
| F                             | -0.06                                                                                | 0.02        | 0.01        | <b>1.00</b> | 0.67        |
| MTD                           | 0.10                                                                                 | -0.25       | 0.34        | 0.67        | <b>1.00</b> |

**Table (4.8) : Correlation Matrix of Rigid pavement for BPN Model.**

| Stat.<br>multiple<br>regress. | Correlations, N=54 (Casewise deletion of missing data)(BPN. Sta)<br>, Rigid pavement |             |             |             |             |
|-------------------------------|--------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|
| variable                      | MAX                                                                                  | WC          | CSG         | F           | BPN         |
| MAX                           | <b>1.00</b>                                                                          | -0.01       | -0.02       | -0.01       | 0.35        |
| WC                            | -0.01                                                                                | <b>1.00</b> | 0.01        | 0.01        | -0.40       |
| CSG                           | -0.02                                                                                | 0.01        | <b>1.00</b> | -0.01       | 0.49        |
| F                             | -0.01                                                                                | 0.01        | -0.01       | <b>1.00</b> | 0.39        |
| BPN                           | 0.35                                                                                 | -0.40       | 0.49        | 0.39        | <b>1.00</b> |

**Table (4.9) : Correlation Matrix of Rigid pavement for F60 Model.**

| Stat.<br>multiple<br>regress. | Correlations, N=54 (Casewise deletion of missing data)(F60. Sta)<br>, Rigid pavement |             |             |             |             |
|-------------------------------|--------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|
| variable                      | MAX                                                                                  | WC          | CSG         | F           | F60         |
| MAX                           | <b>1.00</b>                                                                          | 0.01        | -0.04       | -0.04       | 0.33        |
| WC                            | 0.01                                                                                 | <b>1.00</b> | 0.00        | 0.02        | -0.38       |
| CSG                           | -0.04                                                                                | 0.00        | <b>1.00</b> | -0.02       | 0.49        |
| F                             | -0.04                                                                                | 0.02        | -0.02       | <b>1.00</b> | 0.36        |
| F60                           | 0.33                                                                                 | -0.38       | 0.49        | 0.36        | <b>1.00</b> |

It is clear from Tables (4.7, to 4.9) that:

1. The aggregate maximum size greatly influences the British Pendulum Number (BPN) from the Mean Texture Depth (MTD).
2. The Water to Cement (W/C) ratio more influences the British Pendulum Number (BPN) from the Mean Texture Depth (MTD).
3. The Mix Ratio greatly influences the British Pendulum Number (BPN) from the Mean Texture Depth (MTD).
4. MTD is more influenced by Finishing than BPN.

#### **4.4.2.2 Correlation Matrix of Flexible Pavement**

Correlation Matrix of Flexible pavement for MTD, PBN and F60 are shown in Tables (4.10) to (4.12) respectively.

**Table (4.10) : Correlation Matrix of Flexible pavement for MTD Model.**

| Stat.<br>multiple<br>regress. | Correlations, N=18 (Casewise deletion of missing data)(MTD. Sta)<br>, Flexible pavement |             |             |             |             |             |             |             |
|-------------------------------|-----------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| variable                      | MAX                                                                                     | AC          | P9_5        | P4          | P8          | P50         | G           | MTD         |
| MAX                           | <b>1.00</b>                                                                             | 0.00        | -0.90       | -0.67       | -0.54       | -0.27       | -0.02       | 0.62        |
| AC                            | 0.00                                                                                    | <b>1.00</b> | 0.00        | -0.01       | -0.01       | -0.01       | -0.21       | -0.39       |
| P9_5                          | -0.90                                                                                   | 0.00        | <b>1.00</b> | 0.90        | 0.81        | 0.62        | 0.33        | -0.46       |
| P4                            | -0.67                                                                                   | -0.01       | 0.90        | <b>1.00</b> | 0.98        | 0.89        | 0.58        | -0.21       |
| P8                            | -0.54                                                                                   | -0.01       | 0.81        | 0.98        | <b>1.00</b> | 0.95        | 0.66        | -0.08       |
| P50                           | -0.27                                                                                   | -0.01       | 0.62        | 0.89        | 0.95        | <b>1.00</b> | 0.75        | 0.11        |
| G                             | -0.02                                                                                   | -0.21       | 0.33        | 0.58        | 0.66        | 0.75        | <b>1.00</b> | 0.26        |
| MTD                           | 0.62                                                                                    | -0.39       | -0.46       | -0.21       | -0.08       | 0.11        | 0.26        | <b>1.00</b> |

**Table (4.11) : Correlation Matrix of Flexible pavement for BPN Model.**

| Stat.<br>multiple<br>regress. | Correlations, N=18 (Casewise deletion of missing data)(BPN. Sta)<br>, Flexible pavement |             |             |             |             |             |             |             |
|-------------------------------|-----------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| variable                      | MAX                                                                                     | AC          | P9_5        | P4          | P8          | P50         | G           | BPN         |
| MAX                           | <b>1.00</b>                                                                             | 0.01        | -0.91       | -0.68       | -0.54       | -0.27       | -0.01       | 0.72        |
| AC                            | 0.01                                                                                    | <b>1.00</b> | -0.01       | -0.01       | -0.01       | -0.01       | -0.22       | -0.45       |
| P9_5                          | -0.91                                                                                   | -0.01       | <b>1.00</b> | 0.90        | 0.80        | 0.61        | 0.31        | -0.57       |
| P4                            | -0.68                                                                                   | -0.01       | 0.90        | <b>1.00</b> | 0.98        | 0.89        | 0.57        | -0.30       |
| P8                            | -0.54                                                                                   | -0.01       | 0.80        | 0.98        | <b>1.00</b> | 0.95        | 0.65        | -0.18       |
| P50                           | -0.27                                                                                   | -0.01       | 0.61        | 0.89        | 0.95        | <b>1.00</b> | 0.74        | 0.05        |
| G                             | -0.01                                                                                   | -0.22       | 0.31        | 0.57        | 0.65        | 0.74        | <b>1.00</b> | 0.27        |
| BPN                           | 0.72                                                                                    | -0.45       | -0.57       | -0.30       | -0.18       | 0.05        | 0.27        | <b>1.00</b> |

**Table (4.12) : Correlation Matrix of Flexible pavement for F60 Model.**

| Stat.<br>multiple<br>regress. | Correlations, N=18 (Casewise deletion of missing data)(F60. Sta)<br>, Flexible pavement |             |             |             |             |             |             |             |
|-------------------------------|-----------------------------------------------------------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| variable                      | MAX                                                                                     | AC          | P9_5        | P4          | P8          | P50         | G           | F60         |
| MAX                           | <b>1.00</b>                                                                             | 0.01        | -0.90       | -0.67       | -0.54       | -0.27       | -0.02       | 0.67        |
| AC                            | 0.01                                                                                    | <b>1.00</b> | -0.01       | -0.01       | -0.01       | -0.01       | -0.20       | -0.43       |
| P9_5                          | -0.90                                                                                   | -0.01       | <b>1.00</b> | 0.90        | 0.81        | 0.62        | 0.34        | -0.50       |
| P4                            | -0.67                                                                                   | -0.01       | 0.90        | <b>1.00</b> | 0.98        | 0.89        | 0.59        | -0.24       |
| P8                            | -0.54                                                                                   | -0.01       | 0.81        | 0.98        | <b>1.00</b> | 0.95        | 0.66        | -0.12       |
| P50                           | -0.27                                                                                   | -0.01       | 0.62        | 0.89        | 0.95        | <b>1.00</b> | 0.76        | 0.09        |
| G                             | -0.02                                                                                   | -0.20       | 0.34        | 0.59        | 0.66        | 0.76        | <b>1.00</b> | 0.27        |
| F60                           | 0.67                                                                                    | -0.43       | -0.50       | -0.24       | -0.12       | 0.09        | 0.27        | <b>1.00</b> |

It is clear from Tables (4.10, 4.11 and 4.12) the following:

1. The aggregate maximum size greatly influences the British Pendulum Number (BPN) from the Mean Texture Depth (MTD).
2. The asphalt cement content greatly influences the British Pendulum Number (BPN) from the Mean Texture Depth (MTD).
3. The Coarse Gradation has almost the same effect on BPN, MTD and F60.

#### **4.4.3 Comparison between Rigid and Flexible Pavement with Respect to Aggregate Maximum Size.**

It is clear from Figures (4.1) to (4.19) that Friction number (F60) has greater value in rigid pavement than flexible pavement, But as indicated Correlation Matrix in Tables (4.7) to (4.12), the aggregate maximum size influence on (BPN) of Flexible pavement greater than the influence on Rigid pavement. The aggregate maximum size influence on (MTD) of Flexible pavement has greater influence on rigid pavement.

**Table (4.13) : Results of Rigid pavement for F60 model database.**

| variable | mean   | st. dev. | minimum | maximum |
|----------|--------|----------|---------|---------|
| MAX      | 0.750  | 0.206    | 0.500   | 1.000   |
| CSG      | 2.000  | 0.824    | 1.000   | 3.000   |
| F        | 1.500  | 0.505    | 1.000   | 2.000   |
| WC       | 0.550  | 0.082    | 0.450   | 0.650   |
| F60      | 63.001 | 12.364   | 29.734  | 84.341  |

**Table (4.14) : Results of Flexible pavement for F60 model database.**

| variable | mean   | st. dev. | minimum | maximum |
|----------|--------|----------|---------|---------|
| MAX      | 0.750  | 0.210    | 0.500   | 1.000   |
| AC       | 4.917  | 0.613    | 4.100   | 6.000   |
| G        | 0.500  | 0.786    | 0.000   | 2.000   |
| P9_5     | 82.000 | 12.443   | 56.000  | 100.000 |
| P4       | 59.667 | 12.257   | 35.000  | 85.000  |
| P8       | 42.944 | 10.778   | 23.000  | 67.000  |
| P50      | 13.333 | 4.740    | 5.000   | 23.000  |
| F60      | 40.674 | 6.942    | 27.620  | 51.160  |

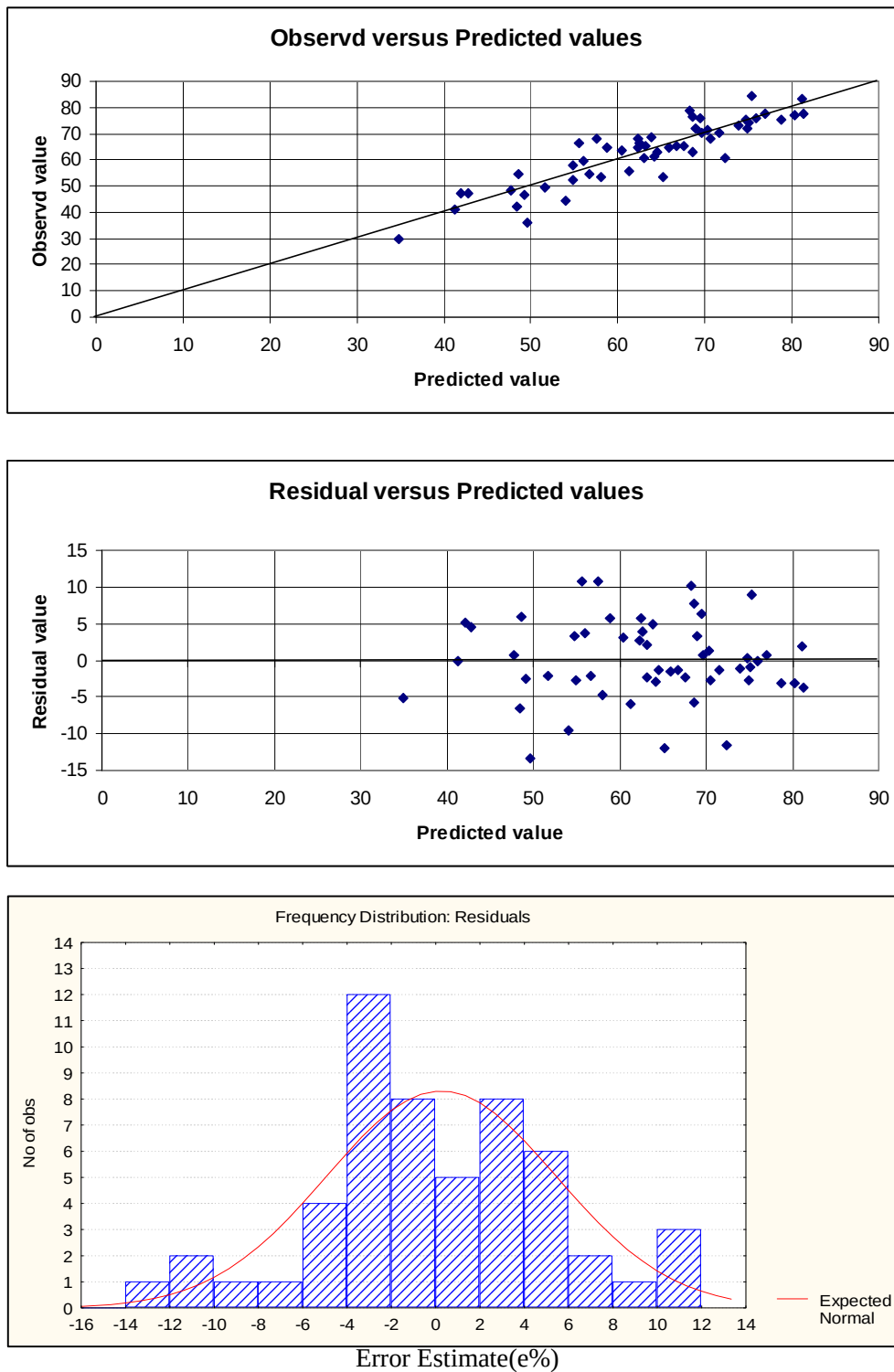


**Figure (4.26) :Diagnostic plots of model F60 of rigid pavement.**

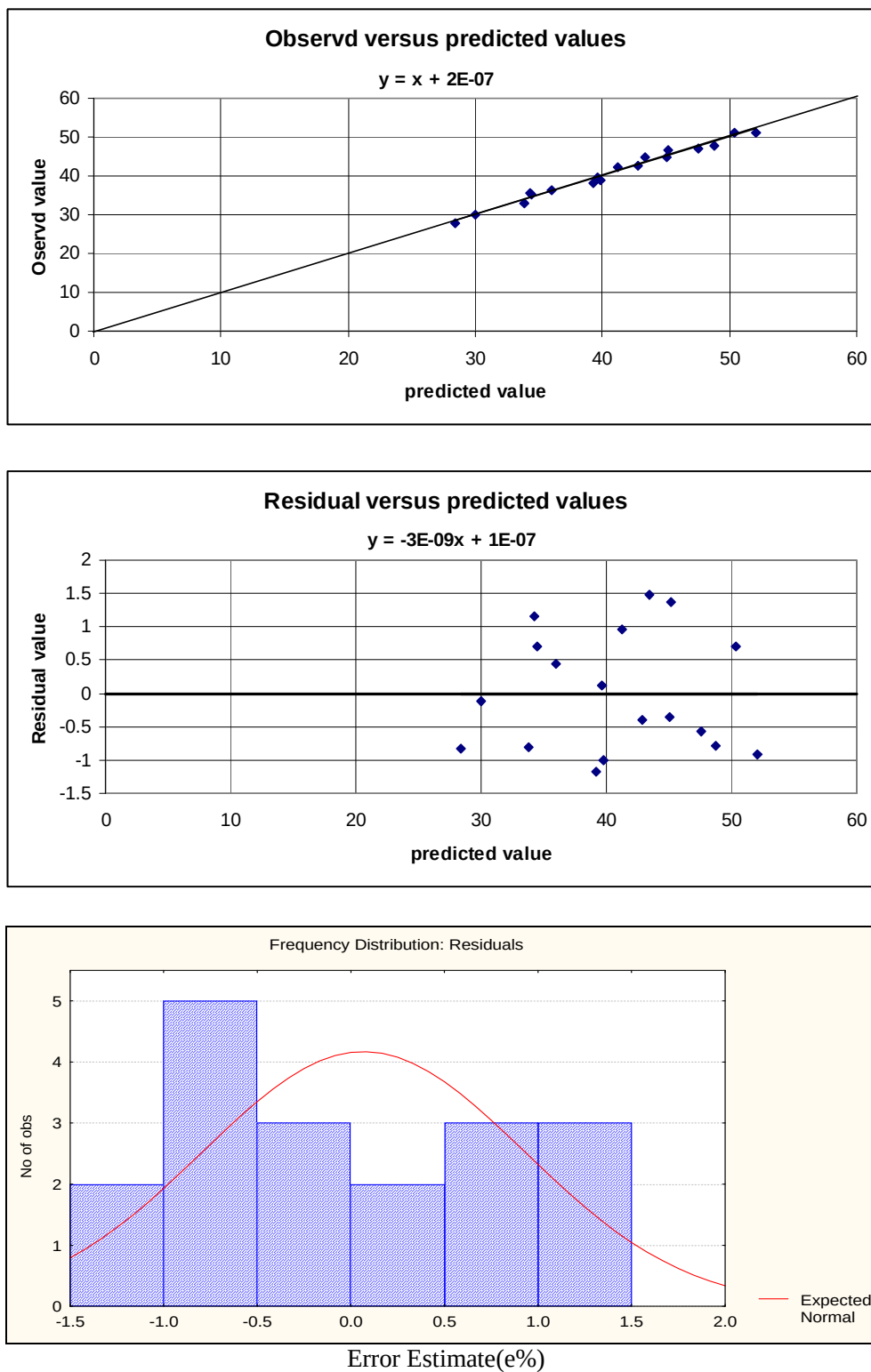


Figure (4.27) :Diagnostic plots of model F60 of Flexible pavement.

Table (4.15): Possible models from the stepwise regression analysis

| Pavement | Models                                                                                         | R <sup>2</sup> |
|----------|------------------------------------------------------------------------------------------------|----------------|
| Rigid    | $F60 = c1 + c2 * \max + c3 * csg + c4 * wc/f + c5 * (f/wc) + c6 * (f/\max) + c7 * f * wc/\max$ | 0.81           |
| Flexible | $F60 = C1 + C2 * \text{Max} + C3 * ac ** 2 + C4 * g ** 2 + C5 * \text{Max} * aC + C6 * ac * g$ | 0.97           |

Where:

$\max$  = max. agg size(1", 3/4" and 1/2")       $wc$  = water to cement ratio(0.45, 0.55, and 0.65)

$f$  = finishing of surface (smooth=1, rough=2)       $g$  = Gradation limit (fine=1, intermediated=2, course=3)

$ac$  = asphalt cement content % (4.1, 4.7, 5.3 and 6.0)       $csg$  = cement to sand to gravel ratio (1:1.5:3=1, 1:2:4=2, 1:3:6=3)

| Coefficient | F60 Rigid pavement | F60 Flexible pavement |
|-------------|--------------------|-----------------------|
| C1          | 42.78082           | 35.38460              |
| C2          | 48.59243           | -4.02142              |
| C3          | 6.39504            | 23.45011              |
| C4          | -61.94430          | -0.45907              |
| C5          | -8.67441           | 10.80577              |
| C6          | 20.94224           | -0.16070              |
| C7          | -20.67757          |                       |

## 4.5 Sound Level Measurements

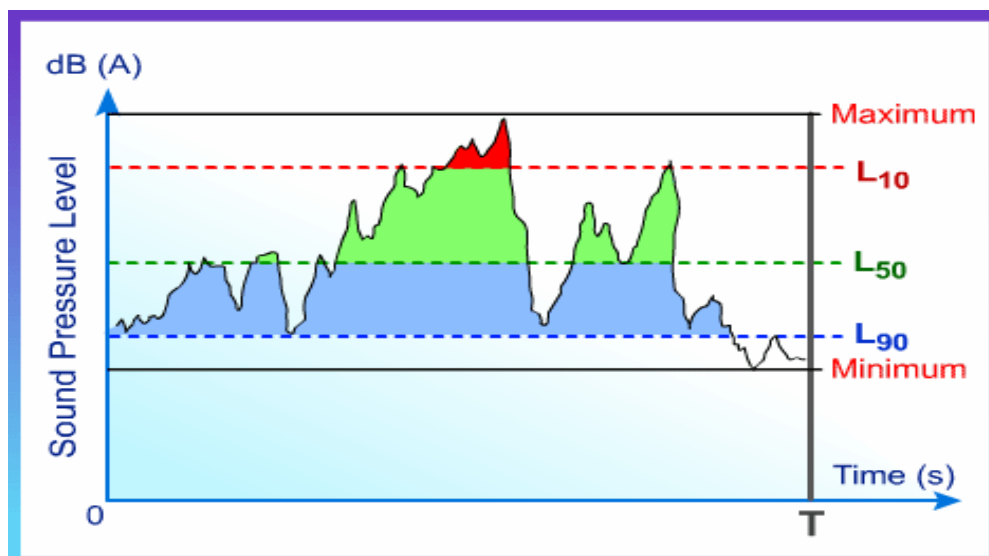
The study summarizes the results obtained from the sound level measurements. The sound level measurements are the Controlled Pass-By (CPB) Method and Statistical Passby (SPB) method. The data of SPB Methods is summarized in Appendix B.

### 4.5.1 Statistical Pass-By Method

Statistical Passby (SPB) methods utilized a random sample of typical vehicles measured through peak hour. It was from 8:15 to 9:15 AM as shown in Table (B) in appendix (B.1).

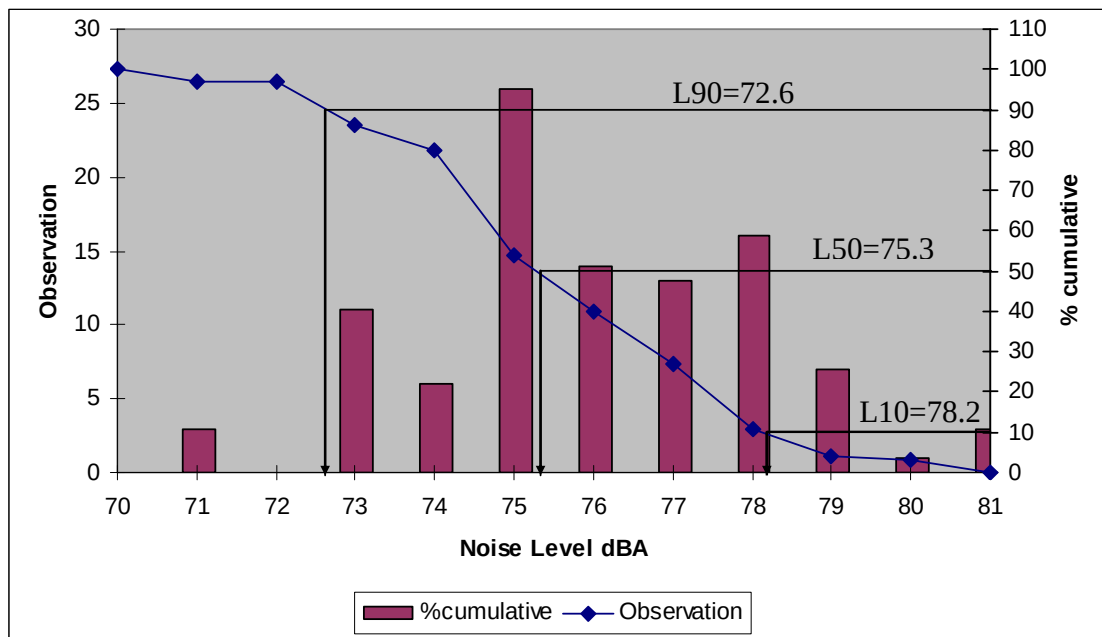
#### 4.5.1.1-Statistical Model for Noise Levels Relationship

Statistical model has been built by taking 100 random viewing of the sound levels in the study area. The obtained cumulative Vistas are used to obtain the relationship(S-curve) between the categories as shown in Figure (4.28) and (4.29) and Table (4.16)



Please note that  $L_{10} > L_{50} > L_{90}$  for the same sound or noise.

Figure (4.28) Illustrates L10, L50 and L90.



**Figure(4.29) : The relationship between observation ,cumulative and noise level**

**Table (4.16):Observation ,cumulative and noise level**

| Faction | Observation | %cumulative | Ln          |
|---------|-------------|-------------|-------------|
| 70      | 0           | 100         | <b>L100</b> |
| 71      | 3           | 97          |             |
| 72      | 0           | 97          |             |
| 73      | 11          | 86          | <b>L86</b>  |
| 74      | 6           | 80          |             |
| 75      | 26          | 54          | <b>L54</b>  |
| 76      | 14          | 40          |             |
| 77      | 13          | 27          |             |
| 78      | 16          | 11          | <b>L11</b>  |
| 79      | 7           | 4           |             |
| 80      | 1           | 3           |             |
| 81      | 3           | 0           |             |

#### 4.5.1.1.1-The Relationship between the Traffic Volume and Noise Levels

Figure (4.30) explain the relationship sound level pressure versus traffic volume in the study area of 40 Street. The results show that the sound level pressure increases as the Traffic volume increases.

In order to reflect the relationship between the traffic volume and noise levels, statistical model is built using the necessary data on traffic volume and other elements of traffic. Table (4.18) shows traffic volume for peak hour and noise levels.

**Table (4.17) Traffic Volume for peak hour and Noise Levels.**

| Time      | L10<br>dbA | L50<br>dbA | L90<br>dbA | Volume<br>(veh) |
|-----------|------------|------------|------------|-----------------|
| 8:15-8:30 | 79.4       | 75.6       | 73.9       | 1544            |
| 8:30-8:45 | 78.4       | 75.8       | 74.8       | 1400            |
| 8:45-9:00 | 78.7       | 76.5       | 75.1       | 1460            |
| 9:00-9:15 | 81.7       | 76.8       | 74.9       | 1868            |

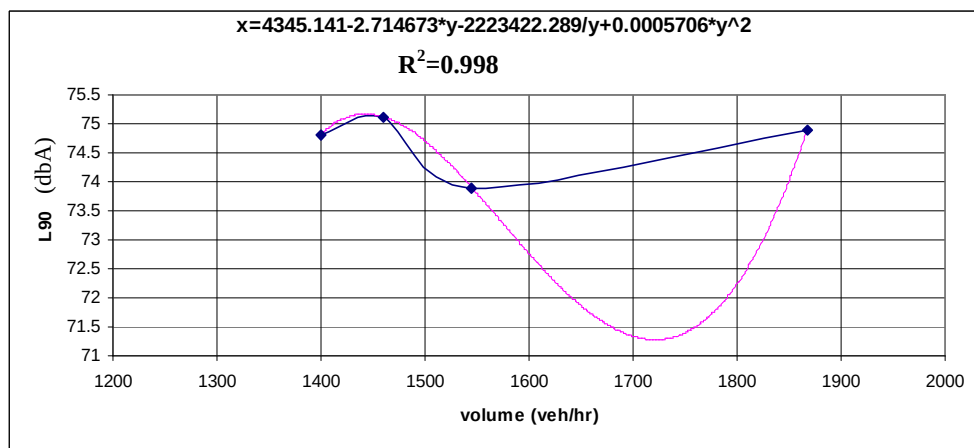
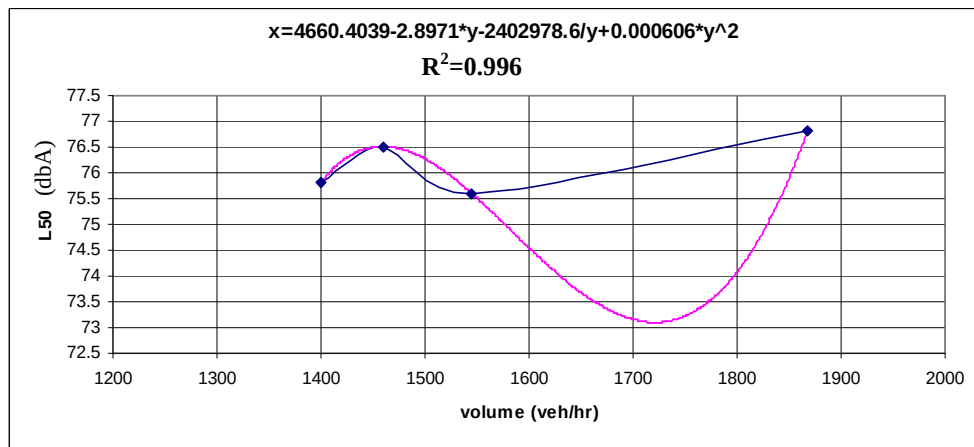
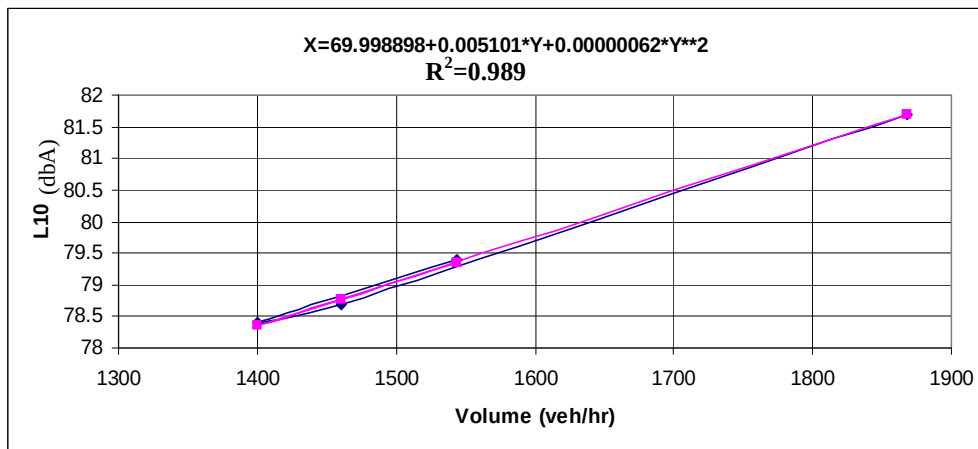


**Figure (4.30): The relationship between traffic volume and noise level.**

#### 4.5.1.1.2-The Relationship between the Speed of Traffic and Noise Levels

Figure (4.31) explains the relationship of sound level pressure versus vehicle speed for the study area of 40 Street. The results show that the sound level pressure increases as the vehicle speed increases. A statistical model is building for the relationship between traffic speed and noise level in the study area. Table (4.19) shows speed of traffic and the changing levels of noise.

**Table (4.18) traffic speed for hour peak and noise levels.**

| <b>Time</b>      | <b>L10<br/>(dbA)</b> | <b>L50<br/>(dbA)</b> | <b>L90<br/>(dbA)</b> | <b>Speed<br/>(km/hr)</b> |
|------------------|----------------------|----------------------|----------------------|--------------------------|
| <b>8:15-8:30</b> | 79.4                 | 75.6                 | 73.9                 | 59                       |
| <b>8:30-8:45</b> | 78.4                 | 75.8                 | 74.8                 | 49                       |
| <b>8:45-9:00</b> | 78.7                 | 76.5                 | 75.1                 | 54                       |
| <b>9:00-9:15</b> | 81.7                 | 76.8                 | 74.9                 | 55                       |

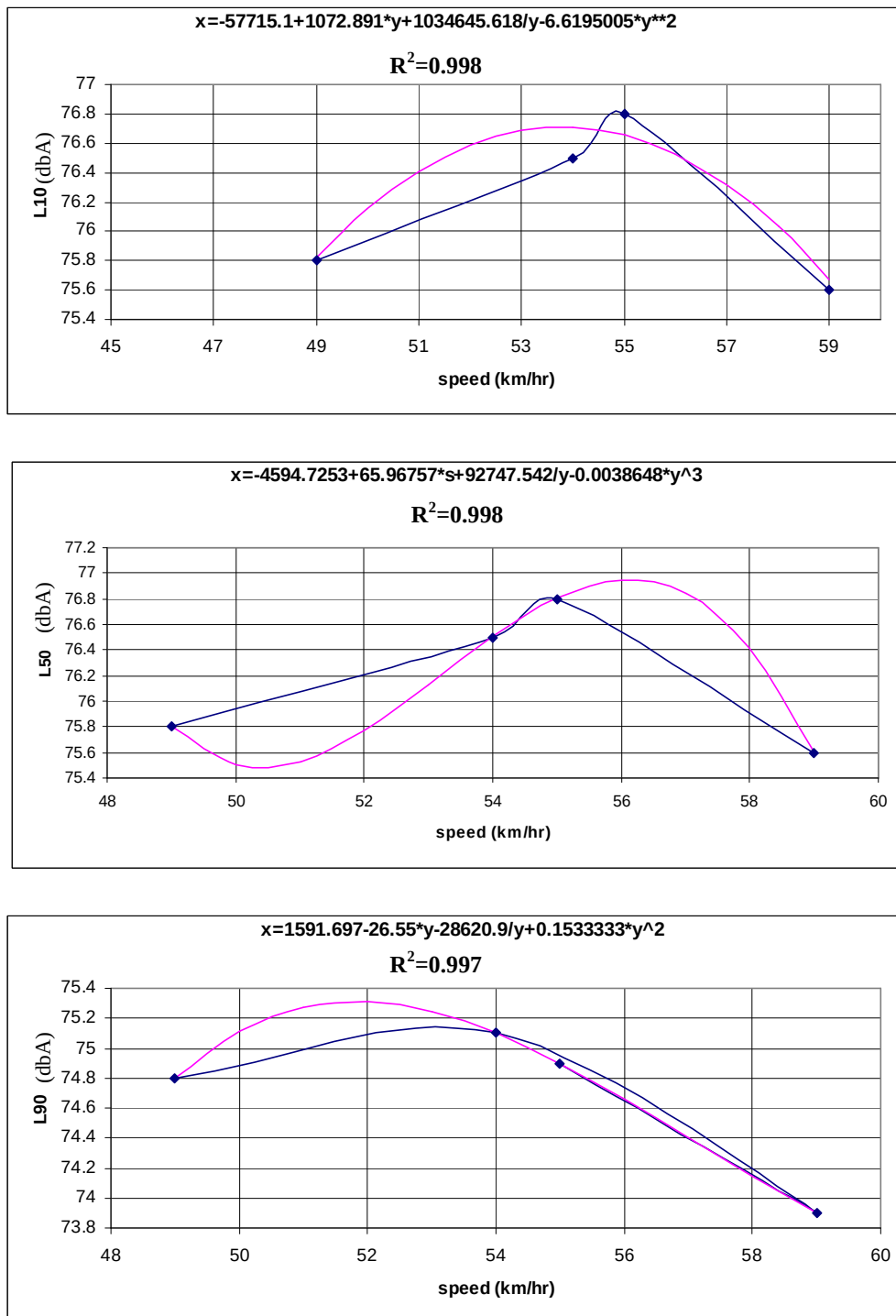


Figure (4.31) : The relationship between traffic speed and noise level.

#### 4.5.1.1.3 The Relationship between Traffic Density and noise Levels

Figure (4.32) explains the relationship of sound level pressure versus traffic density for the study area of 40 Street. It is clear from Figure (4.35) that the density of traffic increases with the increase of sound level pressure. A statistical model is obtained for the relationship between traffic speed and noise level in the study area. Table (4.20) shows traffic density and the changing levels of noise.

**Table (4.19) Traffic density for hour peak and noise levels.**

| <b>Time</b>      | <b>L10<br/>(dbA)</b> | <b>L50<br/>(dbA)</b> | <b>L90<br/>(dbA)</b> | <b>Density<br/>(veh/km)</b> |
|------------------|----------------------|----------------------|----------------------|-----------------------------|
| <b>8:15-8:30</b> | 79.4                 | 75.6                 | 73.9                 | 59                          |
| <b>8:30-8:45</b> | 78.4                 | 75.8                 | 74.8                 | 77                          |
| <b>8:45-9:00</b> | 78.7                 | 76.5                 | 75.1                 | 62                          |
| <b>9:00-9:15</b> | 81.7                 | 76.8                 | 74.9                 | 73                          |

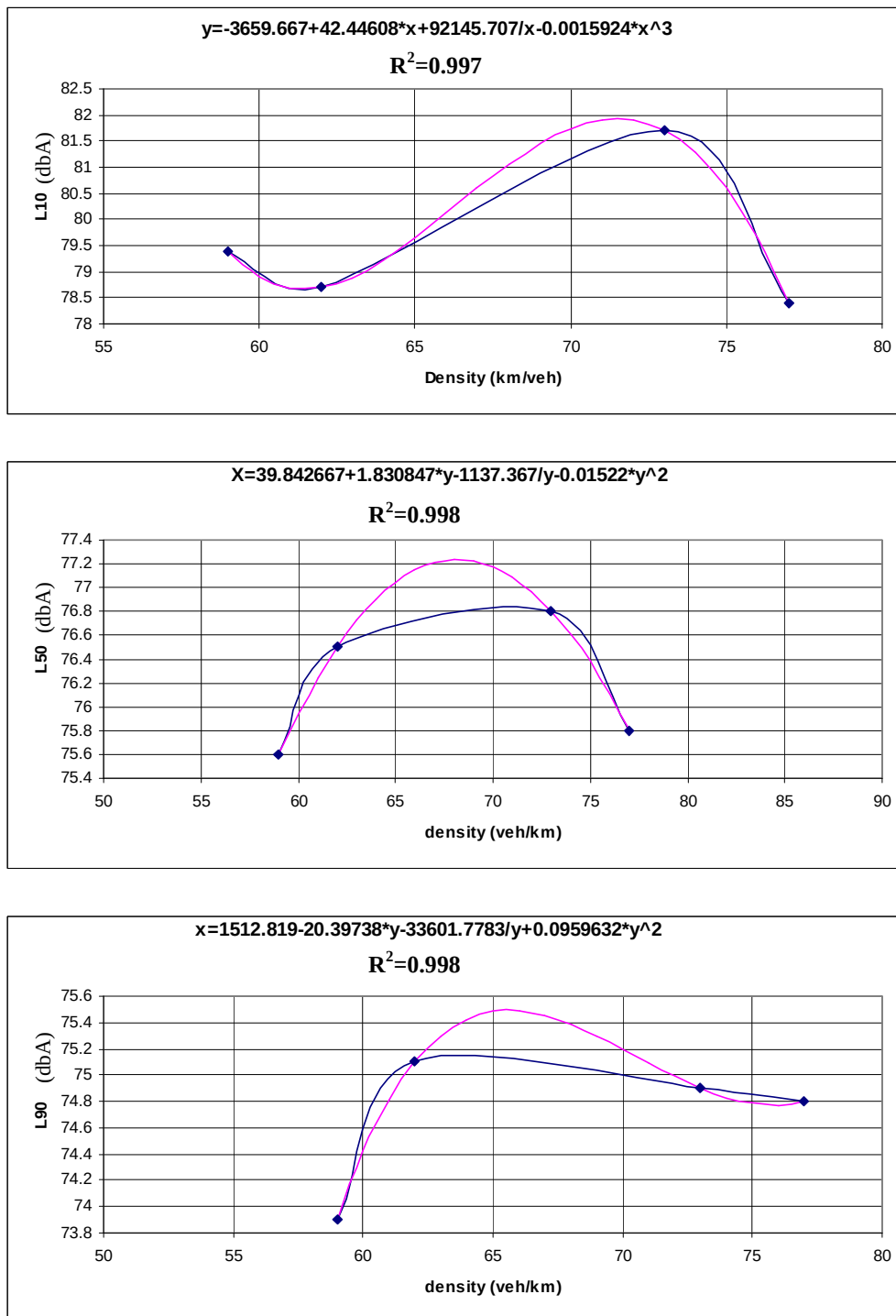


**Figure (4.32): The relationship between traffic density and noise level.**

#### 4.5.1.1.4 Prediction of Noise Levels

The first step in the development of the statistical analysis was selection of the form of the relationship between the dependent and the independent variables:

The dependent variables are: L10, L50, and L90.

The independent variables are: Speed, Traffic Volume and Density.

$$L10=68.037+0.0071*(V+S-1/D) \quad R^2=0.9989$$

$$L50=96.8+0.0055*V-0.359*S-0.1444*D \quad R^2=0.996$$

$$L90=98.39+0.00405*V-0.3879*S-0.1331*D \quad R^2=0.995$$

Where:

V= traffic volume, S= speed of traffic, and D= density of traffic.

#### 4.5.1.1.5 The Relationship between Speed of Traffic and Traffic Density

Figure (4.33) explains the relationship between speed of traffic and traffic density for the study area of 40 Street. It is clear from Figure (4.33) that the greater the traffic density decrease speed of vehicles. Table (4.21) shows traffic density and speed of traffic.

**Table (4.20) Traffic density and traffic speed for hour peak.**

| Time      | Speed<br>(Km/hr) | Density<br>(veh/km) |
|-----------|------------------|---------------------|
| 8:15-8:30 | 59               | 59                  |
| 8:30-8:45 | 49               | 77                  |
| 8:45-9:00 | 54               | 62                  |
| 9:00-9:15 | 55               | 73                  |

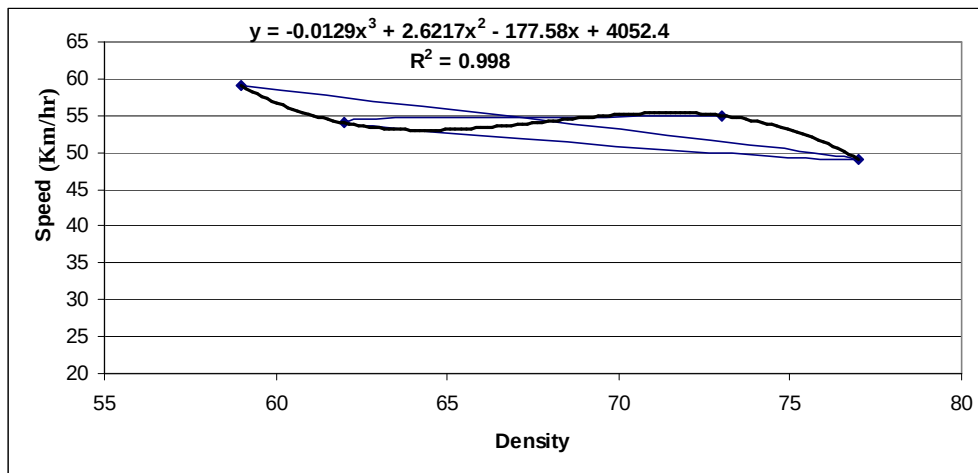


**Figure (4.33 ):** The relationship between traffic density and traffic speed.

#### 4.5.1.2 Controlled Pass-By Method

Controlled Pass-by (CPB) method used one vehicle to move on several different roads of different texture and at different speeds, as indicated in Table (4.22). several results are obtained due to effect of some variables as discussed below.

**Table (4.21) Traffic speed for three street and noise level.**

| Street                | Al- qatheah<br>(Rigid Pavement) |               | Mehazem<br>(Flexible Pavement) |               | 40 street<br>(Flexible Pavement) |               |
|-----------------------|---------------------------------|---------------|--------------------------------|---------------|----------------------------------|---------------|
| Texture depth<br>(mm) | 1.207                           |               | 0.752                          |               | 1.004                            |               |
| Speed<br>(Km/h)       | Noise<br>(dbA)                  | Tuba<br>(dbA) | Noise<br>(dbA)                 | Tuba<br>(dbA) | Noise<br>(dbA)                   | Tuba<br>(dbA) |
| 20                    | 68                              | —             | 66                             | —             | —                                | —             |
| 30                    | 72                              | 83            | 69                             | 81            | 70                               | 80            |
| 40                    | 75                              | 87            | 72                             | 82            | 73                               | 84            |
| 50                    | 81                              | —             | 77                             | —             | 78                               | —             |
| 60                    | —                               | —             | —                              | —             | 82                               | —             |

#### 4.5.1.2.1 Traffic Speed versus Sound Pressure Level .

Figure (4.34) explains the relationship of sound level pressure versus vehicle speed for the study area of 40 Street. The results show that the sound level increases as the vehicle speed increases for all pavement. A statistical model is obtained for the relationship between traffic speed and noise level in the study area. Table (4.23) shows traffic speed and sound level pressure.

**Table (4.22) Traffic speed and noise pursuer level.**

| Speed<br>(km/hr) | SPL<br>(dbA) |
|------------------|--------------|
| 30               | 70           |
| 40               | 73           |
| 50               | 78           |
| 60               | 82           |

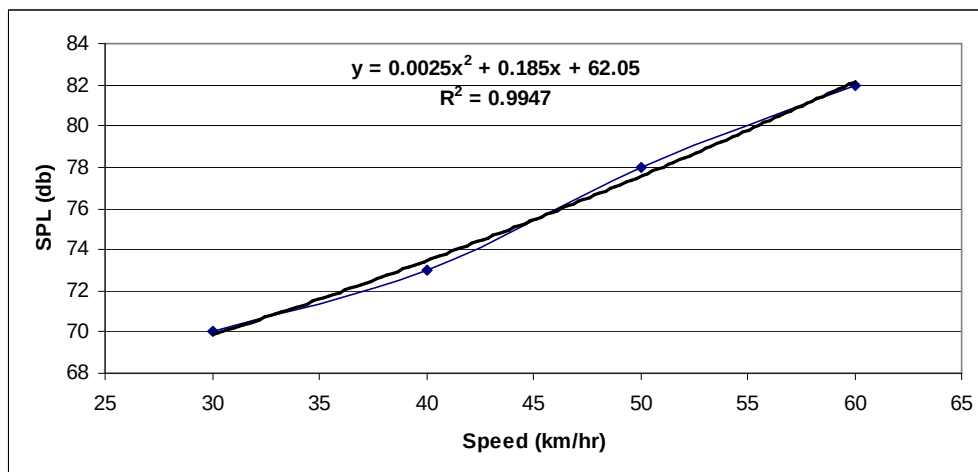


**Figure (4.34): The relationship between traffic speed and noise pressure level (SPL).**

#### 4.5.1.2.2 Texture Depth versus Sound Pressure Level.

Figure (4.35) explains the relationship sound level pressure versus Texture.

It is clear that the sound level pressure increases as texture depth increases. as indicated in Table (4.24). The generated noise from the concrete paving is largest than the noise generated from the asphalt paving by 3.5 db. A statistical model is obtained for the relationship between traffic speed and noise level in the study area.

**Table (4.23) texture depth for three roads and noise pressure level.**

| Texture depth (mm) | SPL (dbA) |
|--------------------|-----------|
| 1.207              | 81        |
| 1.004              | 78        |
| 0.752              | 77        |

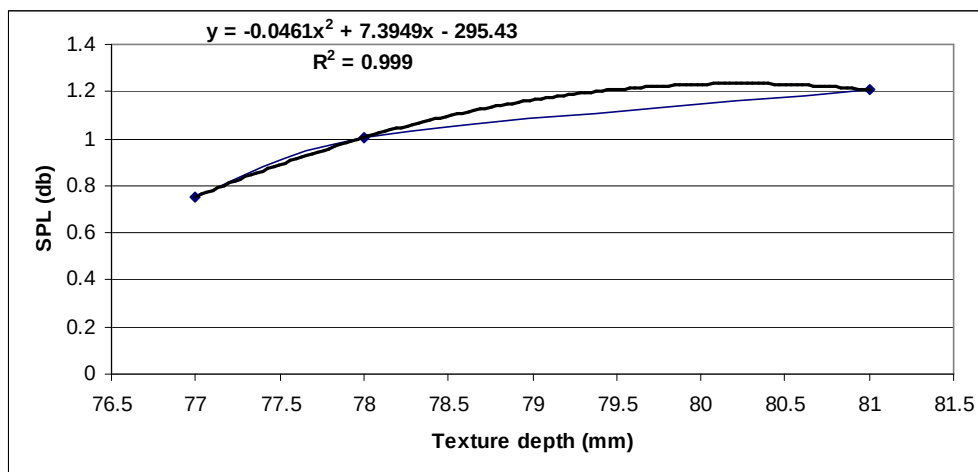


**Figure (4.35): The relationship between texture depth and noise pressure level (SPL).**

# CHAPTER FIVE

## **Conclusions and Recommendations**

# Chapter 5

## Conclusions & Recommendations

### 5.1 Conclusions:

Within the limitations of materials and testing program adopted in this work, the following are concluded:

#### 5.1.1- Skid Resistance

##### 5.1.1.1 – Rigid Pavement

1. Friction Number (F60) has been increased by 103% for increased aggregate maximum size from  $\frac{1}{2}$ " to  $\frac{3}{4}$ " inch.
2. Decreasing the W/C ratio of concrete from 0.55 to 0.45 has increased Friction Number (F60) by 122%.
3. Replacing the smooth by rough as concrete finishing conditions of rigid pavement has increased Friction Number (F60) by 115%.
4. Replacing the wet by dry as surface condition has increased Friction Number (F60) by 133%.
5. Friction Number (F60) has been increased by 112% if replace the mix ratio from 1:1.5:3 to 1:2:4.

##### 5.1.1.2 – Flexible Pavement

1. Increasing asphalt content of paving mixtures from 4.7% to 5.3% causes a decreased Friction Number by 93%.

2. Friction Number (F60) has been increased by 118% for increasing the aggregate maximum size from  $\frac{1}{2}$ " to  $\frac{3}{4}$ "inch.
3. Coarse gradation (lower gradation limit) with maximum Aggregate size of  $\frac{1}{2}$ "inch causes an increased Friction Number (F60) with increased number of cycles by 109%.
4. Replacing the wet by dry as surface condition has increased Friction Number (F60) by 123%.

From the experimental work, it was found that; the variable that possesses more control on the skid resistance of flexible pavement is maximum aggregate size. The variables that possesses more control on the skid resistance of rigid pavement are mix ratio, water/cement ratio and finishing conditions.

### **5.1.2 – Noise Level**

1. Sound level pressure has been increased by 104% for increased in traffic volume from 1400 to 1868 for flexible pavement.
2. The noise level has been increased by 119% and 117% for increase in vehicle speed on rigid pavement and flexible pavement from 20 km/hr to 50 km/hr respectively.
3. Vehicle tuba causes an increased noise level by 117% for passenger car traveled on pavement.
4. The noise pressure level has been increased by 105% for increase in texture depth of pavement.

## 5.2 Recommendations:

After reviewing the outcome of this research study, the following recommendations are made:

- It is recommended to evaluate the influence of using rubber, polymer and polyethylene on skid resistance and noise pressure level.
- using of finite element technical modeling to simulate the British pendulum test.
- It is recommended to determine the relationship between sound level and sound absorption coefficient measurement methods in order to minimize the cost and duration of the evaluation of the pavement acoustical attenuation ability.

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# **APPPNDEX A**

**(Friction Data)**

**Table (A-1) The Results of Skid Resistance for Rigid Pavement for Laboratory tests.**

| <b>Agg. Max Size = 1"                      W/C = 0.65</b> |                  |                                |                                |
|-----------------------------------------------------------|------------------|--------------------------------|--------------------------------|
| <b>Cement-to-Sand-to-Gravels Ratio</b>                    | <b>Finishing</b> | <b>British Pendulum Number</b> | <b>Macrotexture Depth (mm)</b> |
| <b>1:1.5:3</b>                                            | <b>Smooth</b>    | <b>73</b>                      | <b>1.136</b>                   |
|                                                           |                  | <b>75</b>                      | <b>1.136</b>                   |
|                                                           |                  | <b>79</b>                      | <b>0.980</b>                   |
|                                                           |                  | <b>78</b>                      | <b>0.901</b>                   |
|                                                           | <b>Avg.</b>      | <b>76</b>                      | <b>1.038</b>                   |
|                                                           | <b>Rough</b>     | <b>84</b>                      | <b>1.477</b>                   |
|                                                           |                  | <b>86</b>                      | <b>1.587</b>                   |
|                                                           |                  | <b>85</b>                      | <b>1.531</b>                   |
|                                                           |                  | <b>87</b>                      | <b>1.531</b>                   |
|                                                           | <b>Avg.</b>      | <b>86</b>                      | <b>1.532</b>                   |
| <b>1:2:4</b>                                              | <b>Smooth</b>    | <b>81</b>                      | <b>1.102</b>                   |
|                                                           |                  | <b>82</b>                      | <b>1.172</b>                   |
|                                                           |                  | <b>76</b>                      | <b>1.172</b>                   |
|                                                           |                  | <b>76</b>                      | <b>1.062</b>                   |
|                                                           | <b>Avg.</b>      | <b>79</b>                      | <b>1.129</b>                   |
|                                                           | <b>Rough</b>     | <b>76</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>76</b>                      | <b>1.845</b>                   |
|                                                           |                  | <b>75</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>76</b>                      | <b>1.845</b>                   |
|                                                           | <b>Avg.</b>      | <b>76</b>                      | <b>1.883</b>                   |
| <b>1:3:6</b>                                              | <b>Smooth</b>    | <b>89</b>                      | <b>1.587</b>                   |
|                                                           |                  | <b>86</b>                      | <b>1.477</b>                   |
|                                                           |                  | <b>87</b>                      | <b>1.333</b>                   |
|                                                           |                  | <b>85</b>                      | <b>1.172</b>                   |
|                                                           | <b>Avg.</b>      | <b>87</b>                      | <b>1.392</b>                   |
|                                                           | <b>Rough</b>     | <b>92</b>                      | <b>2.370</b>                   |
|                                                           |                  | <b>92</b>                      | <b>2.370</b>                   |
|                                                           |                  | <b>93</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>93</b>                      | <b>1.920</b>                   |
|                                                           | <b>Avg.</b>      | <b>93</b>                      | <b>2.145</b>                   |

**Table (A-1) Continues.**

| <div> <div>Agg. Max Size = 1"</div> <div>W/C = 0.55</div> </div> |           |                         |                         |
|------------------------------------------------------------------|-----------|-------------------------|-------------------------|
| Cement-to-Sand-to-Gravels Ratio                                  | Finishing | British Pendulum Number | Macrotexture Depth (mm) |
| 1:1.5:3                                                          | Smooth    | 85                      | 1.845                   |
|                                                                  |           | 87                      | 1.920                   |
|                                                                  |           | 86                      | 1.920                   |
|                                                                  |           | 87                      | 1.920                   |
|                                                                  | Avg.      | 86                      | 1.901                   |
|                                                                  | Rough     | 96                      | 2.083                   |
|                                                                  |           | 95                      | 2.083                   |
|                                                                  |           | 95                      | 2.370                   |
|                                                                  |           | 96                      | 2.370                   |
|                                                                  | Avg.      | 96                      | 2.227                   |
| 1:2:4                                                            | Smooth    | 86                      | 1.775                   |
|                                                                  |           | 87                      | 1.709                   |
|                                                                  |           | 89                      | 1.646                   |
|                                                                  |           | 89                      | 2.083                   |
|                                                                  | Avg.      | 88                      | 1.803                   |
|                                                                  | Rough     | 89                      | 2.596                   |
|                                                                  |           | 90                      | 2.268                   |
|                                                                  |           | 91                      | 2.370                   |
|                                                                  |           | 90                      | 2.479                   |
|                                                                  | Avg.      | 90                      | 2.428                   |
| 1:3:6                                                            | Smooth    | 90                      | 1.709                   |
|                                                                  |           | 93                      | 1.709                   |
|                                                                  |           | 94                      | 1.709                   |
|                                                                  |           | 95                      | 1.709                   |
|                                                                  | Avg.      | 93                      | 1.709                   |
|                                                                  | Rough     | 99                      | 2.370                   |
|                                                                  |           | 99                      | 2.370                   |
|                                                                  |           | 99                      | 3.000                   |
|                                                                  |           | 97                      | 2.596                   |
|                                                                  | Avg.      | 99                      | 2.584                   |

**Table (A-1) Continues.**

| <div> <div>Agg. Max Size = 1"</div> <div>W/C = 0.45</div> </div> |           |                         |                         |
|------------------------------------------------------------------|-----------|-------------------------|-------------------------|
| Cement-to-Sand-to-Gravels Ratio                                  | Finishing | British Pendulum Number | Macrotexture Depth (mm) |
| 1:1.5:3                                                          | Smooth    | 89                      | 1.427                   |
|                                                                  |           | 87                      | 1.531                   |
|                                                                  |           | 88                      | 1.587                   |
|                                                                  |           | 88                      | 1.333                   |
|                                                                  | Avg.      | 88                      | 1.470                   |
|                                                                  | Rough     | 96                      | 1.920                   |
|                                                                  |           | 96                      | 1.920                   |
|                                                                  |           | 97                      | 1.920                   |
|                                                                  |           | 97                      | 1.775                   |
|                                                                  | Avg.      | 97                      | 1.884                   |
| 1:2:4                                                            | Smooth    | 88                      | 1.333                   |
|                                                                  |           | 86                      | 1.333                   |
|                                                                  |           | 89                      | 1.333                   |
|                                                                  |           | 88                      | 1.333                   |
|                                                                  | Avg.      | 88                      | 1.333                   |
|                                                                  | Rough     | 90                      | 1.920                   |
|                                                                  |           | 90                      | 1.920                   |
|                                                                  |           | 91                      | 1.920                   |
|                                                                  |           | 93                      | 1.920                   |
|                                                                  | Avg.      | 91                      | 1.920                   |
| 1:3:6                                                            | Smooth    | 93                      | 1.920                   |
|                                                                  |           | 95                      | 1.920                   |
|                                                                  |           | 95                      | 1.775                   |
|                                                                  |           | 95                      | 1.646                   |
|                                                                  | Avg.      | 95                      | 1.815                   |
|                                                                  | Rough     | 92                      | 2.596                   |
|                                                                  |           | 92                      | 2.596                   |
|                                                                  |           | 92                      | 2.596                   |
|                                                                  |           | 92                      | 2.596                   |
|                                                                  | Avg.      | 92                      | 2.596                   |

**Table (A-1) Continues.**

| <b>Agg. Max Size = ¾”                      W/C = 0.65</b> |                  |                                |                                |
|-----------------------------------------------------------|------------------|--------------------------------|--------------------------------|
| <b>Cement-to-Sand-to-Gravels Ratio</b>                    | <b>Finishing</b> | <b>British Pendulum Number</b> | <b>Macrotexture Depth (mm)</b> |
| <b>1:1.5:3</b>                                            | <b>Smooth</b>    | <b>69</b>                      | <b>1.038</b>                   |
|                                                           |                  | <b>70</b>                      | <b>1.038</b>                   |
|                                                           |                  | <b>74</b>                      | <b>1.038</b>                   |
|                                                           |                  | <b>74</b>                      | <b>1.038</b>                   |
|                                                           | <b>Avg.</b>      | <b>72</b>                      | <b>1.038</b>                   |
|                                                           | <b>Rough</b>     | <b>80</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>84</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>79</b>                      | <b>1.709</b>                   |
|                                                           |                  | <b>85</b>                      | <b>1.646</b>                   |
|                                                           | <b>Avg.</b>      | <b>82</b>                      | <b>1.799</b>                   |
| <b>1:2:4</b>                                              | <b>Smooth</b>    | <b>77</b>                      | <b>0.750</b>                   |
|                                                           |                  | <b>78</b>                      | <b>0.750</b>                   |
|                                                           |                  | <b>80</b>                      | <b>0.750</b>                   |
|                                                           |                  | <b>77</b>                      | <b>0.750</b>                   |
|                                                           | <b>Avg.</b>      | <b>78</b>                      | <b>0.750</b>                   |
|                                                           | <b>Rough</b>     | <b>86</b>                      | <b>1.038</b>                   |
|                                                           |                  | <b>72</b>                      | <b>1.038</b>                   |
|                                                           |                  | <b>85</b>                      | <b>1.038</b>                   |
|                                                           |                  | <b>80</b>                      | <b>0.980</b>                   |
|                                                           | <b>Avg.</b>      | <b>83</b>                      | <b>1.024</b>                   |
| <b>1:3:6</b>                                              | <b>Smooth</b>    | <b>83</b>                      | <b>1.333</b>                   |
|                                                           |                  | <b>83</b>                      | <b>1.333</b>                   |
|                                                           |                  | <b>78</b>                      | <b>1.333</b>                   |
|                                                           |                  | <b>78</b>                      | <b>1.333</b>                   |
|                                                           | <b>Avg.</b>      | <b>81</b>                      | <b>1.333</b>                   |
|                                                           | <b>Rough</b>     | <b>85</b>                      | <b>2.268</b>                   |
|                                                           |                  | <b>86</b>                      | <b>2.083</b>                   |
|                                                           |                  | <b>86</b>                      | <b>2.268</b>                   |
|                                                           |                  | <b>87</b>                      | <b>1.999</b>                   |
|                                                           | <b>Avg.</b>      | <b>86</b>                      | <b>2.155</b>                   |

**Table (A-1) Continues.**

| <b>Agg. Max Size = ¾”                      W/C = 0.55</b> |                  |                                |                                |
|-----------------------------------------------------------|------------------|--------------------------------|--------------------------------|
| <b>Cement-to-Sand-to-Gravels Ratio</b>                    | <b>Finishing</b> | <b>British Pendulum Number</b> | <b>Macrotexture Depth (mm)</b> |
| <b>1:1.5:3</b>                                            | <b>Smooth</b>    | <b>84</b>                      | <b>1.038</b>                   |
|                                                           |                  | <b>83</b>                      | <b>1.038</b>                   |
|                                                           |                  | <b>84</b>                      | <b>1.136</b>                   |
|                                                           |                  | <b>84</b>                      | <b>0.980</b>                   |
|                                                           | <b>Avg.</b>      | <b>84</b>                      | <b>1.048</b>                   |
|                                                           | <b>Rough</b>     | <b>80</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>84</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>79</b>                      | <b>2.173</b>                   |
|                                                           |                  | <b>85</b>                      | <b>2.173</b>                   |
|                                                           | <b>Avg.</b>      | <b>82</b>                      | <b>2.047</b>                   |
| <b>1:2:4</b>                                              | <b>Smooth</b>    | <b>81</b>                      | <b>1.069</b>                   |
|                                                           |                  | <b>83</b>                      | <b>0.901</b>                   |
|                                                           |                  | <b>83</b>                      | <b>0.980</b>                   |
|                                                           |                  | <b>84</b>                      | <b>0.980</b>                   |
|                                                           | <b>Avg.</b>      | <b>83</b>                      | <b>0.983</b>                   |
|                                                           | <b>Rough</b>     | <b>84</b>                      | <b>2.720</b>                   |
|                                                           |                  | <b>85</b>                      | <b>2.720</b>                   |
|                                                           |                  | <b>85</b>                      | <b>2.479</b>                   |
|                                                           |                  | <b>86</b>                      | <b>2.596</b>                   |
|                                                           | <b>Avg.</b>      | <b>85</b>                      | <b>2.629</b>                   |
| <b>1:3:6</b>                                              | <b>Smooth</b>    | <b>87</b>                      | <b>1.477</b>                   |
|                                                           |                  | <b>87</b>                      | <b>1.646</b>                   |
|                                                           |                  | <b>88</b>                      | <b>1.477</b>                   |
|                                                           |                  | <b>89</b>                      | <b>1.477</b>                   |
|                                                           | <b>Avg.</b>      | <b>88</b>                      | <b>0.996</b>                   |
|                                                           | <b>Rough</b>     | <b>97</b>                      | <b>3.000</b>                   |
|                                                           |                  | <b>98</b>                      | <b>3.000</b>                   |
|                                                           |                  | <b>99</b>                      | <b>3.000</b>                   |
|                                                           |                  | <b>98</b>                      | <b>3.000</b>                   |
|                                                           | <b>Avg.</b>      | <b>98</b>                      | <b>3.000</b>                   |

**Table (A-1) Continues.**

| <div> <div>Agg. Max Size = ¾"</div> <div>W/C = 0.45</div> </div> |           |                         |                         |
|------------------------------------------------------------------|-----------|-------------------------|-------------------------|
| Cement-to-Sand-to-Gravels Ratio                                  | Finishing | British Pendulum Number | Macrotexture Depth (mm) |
| 1:1.5:3                                                          | Smooth    | 82                      | 0.750                   |
|                                                                  |           | 83                      | 0.750                   |
|                                                                  |           | 84                      | 0.750                   |
|                                                                  |           | 84                      | 0.750                   |
|                                                                  | Avg.      | 83                      | 0.750                   |
|                                                                  | Rough     | 87                      | 1.209                   |
|                                                                  |           | 90                      | 1.209                   |
|                                                                  |           | 90                      | 1.209                   |
|                                                                  |           | 89                      | 1.209                   |
|                                                                  | Avg.      | 89                      | 1.209                   |
| 1:2:4                                                            | Smooth    | 87                      | 1.333                   |
|                                                                  |           | 87                      | 1.333                   |
|                                                                  |           | 87                      | 1.427                   |
|                                                                  |           | 87                      | 1.587                   |
|                                                                  | Avg.      | 87                      | 1.420                   |
|                                                                  | Rough     | 90                      | 1.587                   |
|                                                                  |           | 90                      | 1.587                   |
|                                                                  |           | 90                      | 1.587                   |
|                                                                  |           | 91                      | 1.587                   |
|                                                                  | Avg.      | 90                      | 1.587                   |
| 1:3:6                                                            | Smooth    | 88                      | 1.333                   |
|                                                                  |           | 89                      | 1.333                   |
|                                                                  |           | 89                      | 1.587                   |
|                                                                  |           | 89                      | 1.587                   |
|                                                                  | Avg.      | 89                      | 1.460                   |
|                                                                  | Rough     | 91                      | 2.370                   |
|                                                                  |           | 92                      | 2.370                   |
|                                                                  |           | 93                      | 2.370                   |
|                                                                  |           | 93                      | 3.320                   |
|                                                                  | Avg.      | 92                      | 2.608                   |

**Table (A-1) Continues.**

| <b>Agg. Max Size = ½”                      W/C = 0.65</b> |                  |                                |                                |
|-----------------------------------------------------------|------------------|--------------------------------|--------------------------------|
| <b>Cement-to-Sand-to-Gravels Ratio</b>                    | <b>Finishing</b> | <b>British Pendulum Number</b> | <b>Macrotexture Depth (mm)</b> |
| <b>1:1.5:3</b>                                            | <b>Smooth</b>    | <b>64</b>                      | <b>0.597</b>                   |
|                                                           |                  | <b>65</b>                      | <b>0.533</b>                   |
|                                                           |                  | <b>61</b>                      | <b>0.680</b>                   |
|                                                           |                  | <b>71</b>                      | <b>0.577</b>                   |
|                                                           | <b>Avg.</b>      | <b>65</b>                      | <b>0.597</b>                   |
|                                                           | <b>Rough</b>     | <b>76</b>                      | <b>1.316</b>                   |
|                                                           |                  | <b>74</b>                      | <b>1.316</b>                   |
|                                                           |                  | <b>78</b>                      | <b>1.316</b>                   |
|                                                           |                  | <b>76</b>                      | <b>1.316</b>                   |
|                                                           | <b>Avg.</b>      | <b>76</b>                      | <b>1.316</b>                   |
| <b>1:2:4</b>                                              | <b>Smooth</b>    | <b>78</b>                      | <b>0.750</b>                   |
|                                                           |                  | <b>79</b>                      | <b>0.697</b>                   |
|                                                           |                  | <b>76</b>                      | <b>0.789</b>                   |
|                                                           |                  | <b>75</b>                      | <b>0.680</b>                   |
|                                                           | <b>Avg.</b>      | <b>78</b>                      | <b>0.729</b>                   |
|                                                           | <b>Rough</b>     | <b>84</b>                      | <b>1.531</b>                   |
|                                                           |                  | <b>83</b>                      | <b>1.209</b>                   |
|                                                           |                  | <b>83</b>                      | <b>1.333</b>                   |
|                                                           |                  | <b>84</b>                      | <b>1.427</b>                   |
|                                                           | <b>Avg.</b>      | <b>84</b>                      | <b>1.375</b>                   |
| <b>1:3:6</b>                                              | <b>Smooth</b>    | <b>81</b>                      | <b>0.853</b>                   |
|                                                           |                  | <b>81</b>                      | <b>0.952</b>                   |
|                                                           |                  | <b>81</b>                      | <b>0.901</b>                   |
|                                                           |                  | <b>82</b>                      | <b>0.853</b>                   |
|                                                           | <b>Avg.</b>      | <b>81</b>                      | <b>0.890</b>                   |
|                                                           | <b>Rough</b>     | <b>93</b>                      | <b>1.587</b>                   |
|                                                           |                  | <b>94</b>                      | <b>2.370</b>                   |
|                                                           |                  | <b>95</b>                      | <b>2.083</b>                   |
|                                                           |                  | <b>96</b>                      | <b>1.920</b>                   |
|                                                           | <b>Avg.</b>      | <b>95</b>                      | <b>1.990</b>                   |

**Table (A-1) Continues.**

| <b>Agg. Max Size = ½”                      W/C = 0.55</b> |                  |                                |                                |
|-----------------------------------------------------------|------------------|--------------------------------|--------------------------------|
| <b>Cement-to-Sand-to-Gravels Ratio</b>                    | <b>Finishing</b> | <b>British Pendulum Number</b> | <b>Macrotexture Depth (mm)</b> |
| <b>1:1.5:3</b>                                            | <b>Smooth</b>    | <b>78</b>                      | <b>0.980</b>                   |
|                                                           |                  | <b>75</b>                      | <b>1.008</b>                   |
|                                                           |                  | <b>76</b>                      | <b>0.901</b>                   |
|                                                           |                  | <b>76</b>                      | <b>0.901</b>                   |
|                                                           | <b>Avg.</b>      | <b>76</b>                      | <b>0.948</b>                   |
|                                                           | <b>Rough</b>     | <b>83</b>                      | <b>1.775</b>                   |
|                                                           |                  | <b>84</b>                      | <b>1.845</b>                   |
|                                                           |                  | <b>83</b>                      | <b>1.775</b>                   |
|                                                           |                  | <b>83</b>                      | <b>1.845</b>                   |
|                                                           | <b>Avg.</b>      | <b>83</b>                      | <b>1.810</b>                   |
| <b>1:2:4</b>                                              | <b>Smooth</b>    | <b>76</b>                      | <b>0.926</b>                   |
|                                                           |                  | <b>77</b>                      | <b>0.952</b>                   |
|                                                           |                  | <b>77</b>                      | <b>0.877</b>                   |
|                                                           |                  | <b>77</b>                      | <b>0.853</b>                   |
|                                                           | <b>Avg.</b>      | <b>77</b>                      | <b>0.902</b>                   |
|                                                           | <b>Rough</b>     | <b>87</b>                      | <b>2.268</b>                   |
|                                                           |                  | <b>85</b>                      | <b>2.268</b>                   |
|                                                           |                  | <b>84</b>                      | <b>2.268</b>                   |
|                                                           |                  | <b>84</b>                      | <b>2.268</b>                   |
|                                                           | <b>Avg.</b>      | <b>85</b>                      | <b>2.268</b>                   |
| <b>1:3:6</b>                                              | <b>Smooth</b>    | <b>86</b>                      | <b>1.587</b>                   |
|                                                           |                  | <b>87</b>                      | <b>1.587</b>                   |
|                                                           |                  | <b>88</b>                      | <b>1.587</b>                   |
|                                                           |                  | <b>89</b>                      | <b>1.531</b>                   |
|                                                           | <b>Avg.</b>      | <b>88</b>                      | <b>1.573</b>                   |
|                                                           | <b>Rough</b>     | <b>95</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>94</b>                      | <b>1.920</b>                   |
|                                                           |                  | <b>95</b>                      | <b>2.083</b>                   |
|                                                           |                  | <b>95</b>                      | <b>2.083</b>                   |
|                                                           | <b>Avg.</b>      | <b>95</b>                      | <b>2.002</b>                   |

**Table (A-1) Continues.**

| <b>Agg. Max Size = ½”                      W/C = 0.45</b> |                  |                                |                                |
|-----------------------------------------------------------|------------------|--------------------------------|--------------------------------|
| <b>Cement-to-Sand-to-Gravels Ratio</b>                    | <b>Finishing</b> | <b>British Pendulum Number</b> | <b>Macrotexture Depth (mm)</b> |
| <b>1:1.5:3</b>                                            | <b>Smooth</b>    | <b>73</b>                      | <b>0.697</b>                   |
|                                                           |                  | <b>75</b>                      | <b>0.593</b>                   |
|                                                           |                  | <b>75</b>                      | <b>0.649</b>                   |
|                                                           |                  | <b>76</b>                      | <b>0.649</b>                   |
|                                                           | <b>Avg.</b>      | <b>75</b>                      | <b>0.647</b>                   |
|                                                           | <b>Rough</b>     | <b>82</b>                      | <b>1.775</b>                   |
|                                                           |                  | <b>82</b>                      | <b>1.845</b>                   |
|                                                           |                  | <b>83</b>                      | <b>1.775</b>                   |
|                                                           |                  | <b>83</b>                      | <b>1.775</b>                   |
|                                                           | <b>Avg.</b>      | <b>83</b>                      | <b>1.793</b>                   |
| <b>1:2:4</b>                                              | <b>Smooth</b>    | <b>80</b>                      | <b>1.587</b>                   |
|                                                           |                  | <b>80</b>                      | <b>1.477</b>                   |
|                                                           |                  | <b>81</b>                      | <b>1.333</b>                   |
|                                                           |                  | <b>82</b>                      | <b>1.333</b>                   |
|                                                           | <b>Avg.</b>      | <b>81</b>                      | <b>1.433</b>                   |
|                                                           | <b>Rough</b>     | <b>84</b>                      | <b>3.000</b>                   |
|                                                           |                  | <b>84</b>                      | <b>3.000</b>                   |
|                                                           |                  | <b>84</b>                      | <b>3.000</b>                   |
|                                                           |                  | <b>84</b>                      | <b>3.000</b>                   |
|                                                           | <b>Avg.</b>      | <b>84</b>                      | <b>3.000</b>                   |
| <b>1:3:6</b>                                              | <b>Smooth</b>    | <b>90</b>                      | <b>1.427</b>                   |
|                                                           |                  | <b>91</b>                      | <b>1.709</b>                   |
|                                                           |                  | <b>91</b>                      | <b>1.709</b>                   |
|                                                           |                  | <b>89</b>                      | <b>1.587</b>                   |
|                                                           | <b>Avg.</b>      | <b>90</b>                      | <b>1.608</b>                   |
|                                                           | <b>Rough</b>     | <b>92</b>                      | <b>2.370</b>                   |
|                                                           |                  | <b>92</b>                      | <b>2.370</b>                   |
|                                                           |                  | <b>93</b>                      | <b>2.370</b>                   |
|                                                           |                  | <b>93</b>                      | <b>2.370</b>                   |
|                                                           | <b>Avg.</b>      | <b>93</b>                      | <b>2.370</b>                   |

**Table (A-2) The Results of Skid Resistance of Rigid Pavement for field tests (Al- QATHEAH).**

| STA.  | BRITISH PENDULUM NUMBER |     | MACROTEXTURE DEPTH (MM) |
|-------|-------------------------|-----|-------------------------|
|       | Dry                     | Wet |                         |
| 0+00  | 84                      | 69  | 1.004                   |
|       | 85                      | 70  | 1.004                   |
|       | 85                      | 73  | 1.124                   |
|       | 82                      | 74  | 1.153                   |
| Avg.  | 84                      | 72  | 1.071                   |
| 0+50  | 81                      | 64  | 0.675                   |
|       | 84                      | 71  | 0.710                   |
|       | 84                      | 71  | 0.710                   |
|       | 84                      | 72  | 0.689                   |
| Avg.  | 83                      | 70  | 0.696                   |
| 0+100 | 84                      | 69  | 0.980                   |
|       | 83                      | 73  | 1.004                   |
|       | 85                      | 69  | 0.968                   |
|       | 84                      | 70  | 0.968                   |
| Avg.  | 84                      | 70  | 0.980                   |
| 0+150 | 86                      | 65  | 1.055                   |
|       | 86                      | 71  | 0.934                   |
|       | 86                      | 74  | 0.957                   |
|       | 87                      | 76  | 1.055                   |
| Avg.  | 86                      | 72  | 1.000                   |
| 0+200 | 89                      | 65  | 2.231                   |
|       | 92                      | 66  | 2.152                   |
|       | 89                      | 64  | 2.315                   |
|       | 89                      | 66  | 2.450                   |
| Avg.  | 90                      | 65  | 2.287                   |

cement-to-sand-to-gravels ratio 1:2:4

Max . agg size 3/4"

W/C = 0.55

**Table (A-3) The Results of Skid Resistance of Rigid Pavement for field tests (AL-THEORA).**

| STA.  | BRITISH PENDULUM NUMBER |     | MACROTEXTURE DEPTH (MM) |
|-------|-------------------------|-----|-------------------------|
|       | Dry                     | Wet |                         |
| 0+00  | 87                      | 76  | 0.872                   |
|       | 91                      | 78  | 0.913                   |
|       | 87                      | 78  | 0.862                   |
|       | 85                      | 76  | 0.892                   |
| Avg.  | 88                      | 77  | 0.885                   |
| 0+50  | 95                      | 66  | 1.200                   |
|       | 94                      | 73  | 1.200                   |
|       | 94                      | 74  | 1.138                   |
|       | 91                      | 75  | 1.109                   |
| Avg.  | 94                      | 72  | 1.162                   |
| 0+100 | 92                      | 66  | 0.913                   |
|       | 94                      | 65  | 0.913                   |
|       | 91                      | 67  | 0.892                   |
|       | 93                      | 70  | 0.902                   |
| Avg.  | 93                      | 67  | 0.905                   |
| 0+150 | 81                      | 66  | 1.728                   |
|       | 84                      | 69  | 1.875                   |
|       | 89                      | 70  | 1.728                   |
|       | 95                      | 70  | 1.598                   |
| Avg.  | 88                      | 69  | 1.732                   |
| 0+200 | 91                      | 60  | 1.153                   |
|       | 92                      | 66  | 1.055                   |
|       | 90                      | 67  | 1.138                   |
|       | 90                      | 66  | 1.138                   |
| Avg.  | 91                      | 65  | 1.121                   |

cement-to-sand-to-gravels ratio 1:2:4

Max . agg size 3/4"

W/C = 0.53

**Table (A-4) The Results of Skid Resistance of Flexible Pavement for field tests (MEHAZEM).**

| STA.  | BRITISH PENDULUM NUMBER |     | MACROTEXTURE DEPTH (MM) |
|-------|-------------------------|-----|-------------------------|
|       | Dry                     | Wet |                         |
| 0+00  | 85                      | 67  | 0.612                   |
|       | 86                      | 74  | 0.558                   |
|       | 86                      | 74  | 0.624                   |
|       | 85                      | 77  | 0.612                   |
| Avg.  | 86                      | 73  | 0.602                   |
| 0+50  | 77                      | 55  | 1.200                   |
|       | 77                      | 59  | 1.016                   |
|       | 77                      | 64  | 0.934                   |
|       | 77                      | 64  | 1.082                   |
| Avg.  | 77                      | 61  | 1.058                   |
| 0+100 | 80                      | 70  | 0.675                   |
|       | 80                      | 71  | 0.643                   |
|       | 78                      | 72  | 0.612                   |
|       | 79                      | 73  | 0.612                   |
| Avg.  | 80                      | 72  | 0.636                   |
| 0+150 | 85                      | 55  | 0.675                   |
|       | 87                      | 61  | 0.612                   |
|       | 87                      | 65  | 0.643                   |
|       | 97                      | 67  | 0.675                   |
| Avg.  | 87                      | 62  | 0.651                   |
| 0+200 | 86                      | 65  | 0.833                   |
|       | 83                      | 74  | 0.882                   |
|       | 84                      | 76  | 0.748                   |
|       | 85                      | 76  | 0.798                   |
| Avg.  | 85                      | 73  | 0.815                   |

Max. Aggregate Size = 1”  
Asphalt content = 4.25 %

# **APPPNDEX B**

**(Noise Level Data)**

Table (B-1) the results of Statistical Passby (SPB) methods.

| TIME    | db(A))(Sound Pressure Level |    |    |    |    |    |    |    |    |    |
|---------|-----------------------------|----|----|----|----|----|----|----|----|----|
| SEC MIN | 1                           | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
| 5       | 75                          | 69 | 74 | 76 | 68 | 62 | 79 | 70 | 74 | 73 |
| 10      | 77                          | 78 | 77 | 73 | 66 | 60 | 83 | 81 | 70 | 75 |
| 15      | 74                          | 80 | 81 | 73 | 72 | 78 | 67 | 70 | 69 | 76 |
| 20      | 76                          | 76 | 74 | 76 | 75 | 65 | 77 | 71 | 66 | 75 |
| 25      | 74                          | 72 | 72 | 67 | 80 | 69 | 77 | 78 | 75 | 78 |
| 30      | 75                          | 77 | 75 | 82 | 80 | 70 | 75 | 72 | 76 | 76 |
| 35      | 73                          | 78 | 75 | 73 | 76 | 75 | 75 | 75 | 75 | 75 |
| 40      | 82                          | 76 | 78 | 81 | 70 | 69 | 72 | 78 | 75 | 73 |
| 45      | 75                          | 78 | 79 | 78 | 88 | 80 | 81 | 75 | 76 | 75 |
| 50      | 78                          | 76 | 78 | 77 | 78 | 79 | 74 | 77 | 87 | 71 |
| 55      | 75                          | 75 | 75 | 78 | 75 | 77 | 77 | 75 | 73 | 73 |
| 60      | 76                          | 76 | 84 | 70 | 65 | 74 | 76 | 72 | 74 | 68 |

| Time |     | db(A))(Sound Pressure Level |    |    |    |    |    |    |    |    |    |
|------|-----|-----------------------------|----|----|----|----|----|----|----|----|----|
| Sec  | Min | 11                          | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 5    |     | 76                          | 75 | 78 | 81 | 66 | 72 | 76 | 76 | 75 | 77 |
| 10   |     | 73                          | 76 | 78 | 75 | 76 | 75 | 76 | 77 | 76 | 76 |
| 15   |     | 76                          | 75 | 80 | 73 | 69 | 76 | 75 | 76 | 69 | 75 |
| 20   |     | 67                          | 75 | 77 | 80 | 65 | 74 | 75 | 76 | 77 | 76 |
| 25   |     | 76                          | 67 | 78 | 80 | 74 | 79 | 77 | 75 | 70 | 77 |
| 30   |     | 75                          | 68 | 77 | 77 | 74 | 70 | 78 | 77 | 79 | 76 |
| 35   |     | 78                          | 76 | 77 | 76 | 68 | 80 | 70 | 72 | 77 | 70 |
| 40   |     | 75                          | 78 | 81 | 73 | 68 | 75 | 75 | 73 | 76 | 74 |
| 45   |     | 77                          | 74 | 77 | 70 | 77 | 75 | 75 | 76 | 74 | 76 |
| 50   |     | 76                          | 74 | 79 | 66 | 75 | 78 | 79 | 73 | 76 | 75 |
| 55   |     | 79                          | 79 | 74 | 73 | 75 | 74 | 77 | 75 | 80 | 75 |
| 60   |     | 76                          | 80 | 75 | 76 | 72 | 75 | 73 | 75 | 75 | 76 |

| Time      | db(A))(Sound Pressure Level |    |    |    |    |    |    |    |    |    |
|-----------|-----------------------------|----|----|----|----|----|----|----|----|----|
| Sec / Min | 21                          | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 5         | 77                          | 81 | 75 | 76 | 73 | 74 | 80 | 75 | 74 | 73 |
| 10        | 76                          | 77 | 70 | 76 | 72 | 76 | 77 | 75 | 76 | 74 |
| 15        | 75                          | 74 | 68 | 75 | 76 | 76 | 70 | 75 | 75 | 75 |
| 20        | 75                          | 72 | 77 | 74 | 75 | 77 | 74 | 74 | 76 | 74 |
| 25        | 75                          | 78 | 75 | 75 | 74 | 78 | 77 | 75 | 76 | 73 |
| 30        | 74                          | 77 | 76 | 73 | 75 | 80 | 74 | 75 | 75 | 77 |
| 35        | 70                          | 76 | 76 | 75 | 75 | 79 | 75 | 73 | 75 | 70 |
| 40        | 76                          | 75 | 76 | 75 | 75 | 71 | 75 | 76 | 74 | 71 |
| 45        | 80                          | 71 | 75 | 75 | 76 | 77 | 74 | 77 | 70 | 75 |
| 50        | 79                          | 76 | 74 | 70 | 77 | 76 | 77 | 78 | 74 | 76 |
| 55        | 76                          | 76 | 78 | 73 | 73 | 81 | 78 | 70 | 77 | 75 |
| 60        | 77                          | 77 | 77 | 76 | 73 | 75 | 75 | 72 | 77 | 76 |

| TIME |     | db(A))(Sound Pressure Level |    |    |    |    |    |    |    |    |    |
|------|-----|-----------------------------|----|----|----|----|----|----|----|----|----|
| SEC  | MIN | 31                          | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| 5    |     | 75                          | 75 | 75 | 77 | 78 | 78 | 80 | 76 | 81 | 73 |
| 10   |     | 74                          | 75 | 76 | 79 | 70 | 78 | 79 | 76 | 79 | 72 |
| 15   |     | 76                          | 73 | 78 | 78 | 79 | 77 | 75 | 75 | 77 | 75 |
| 20   |     | 77                          | 74 | 79 | 77 | 78 | 79 | 73 | 74 | 80 | 75 |
| 25   |     | 78                          | 76 | 80 | 78 | 77 | 76 | 74 | 75 | 73 | 77 |
| 30   |     | 73                          | 77 | 78 | 79 | 76 | 77 | 75 | 75 | 74 | 79 |
| 35   |     | 74                          | 70 | 77 | 81 | 75 | 75 | 75 | 76 | 68 | 83 |
| 40   |     | 75                          | 71 | 77 | 73 | 75 | 76 | 76 | 78 | 70 | 76 |
| 45   |     | 75                          | 73 | 78 | 74 | 74 | 77 | 77 | 81 | 73 | 77 |
| 50   |     | 75                          | 75 | 81 | 75 | 74 | 77 | 74 | 75 | 75 | 76 |
| 55   |     | 76                          | 68 | 76 | 70 | 71 | 78 | 76 | 80 | 75 | 77 |
| 60   |     | 77                          | 67 | 77 | 78 | 76 | 79 | 75 | 78 | 77 | 75 |

| Time |     | db(A))(Sound Pressure Level |    |    |    |    |    |    |    |    |    |
|------|-----|-----------------------------|----|----|----|----|----|----|----|----|----|
| Sec  | Min | 41                          | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 |
| 5    |     | 77                          | 75 | 76 | 75 | 68 | 75 | 74 | 65 | 72 | 74 |
| 10   |     | 76                          | 75 | 76 | 74 | 69 | 75 | 77 | 69 | 66 | 71 |
| 15   |     | 77                          | 74 | 75 | 73 | 76 | 74 | 80 | 83 | 72 | 68 |
| 20   |     | 75                          | 75 | 76 | 73 | 75 | 74 | 74 | 77 | 75 | 67 |
| 25   |     | 75                          | 76 | 75 | 74 | 75 | 76 | 73 | 75 | 80 | 75 |
| 30   |     | 74                          | 77 | 74 | 75 | 77 | 77 | 75 | 72 | 79 | 76 |
| 35   |     | 76                          | 76 | 75 | 75 | 76 | 74 | 75 | 81 | 76 | 75 |
| 40   |     | 78                          | 78 | 76 | 74 | 74 | 73 | 78 | 74 | 71 | 76 |
| 45   |     | 77                          | 75 | 75 | 74 | 75 | 76 | 79 | 77 | 81 | 87 |
| 50   |     | 78                          | 76 | 76 | 74 | 73 | 74 | 78 | 76 | 78 | 73 |
| 55   |     | 77                          | 78 | 75 | 73 | 76 | 75 | 81 | 77 | 75 | 74 |
| 60   |     | 76                          | 76 | 75 | 72 | 75 | 74 | 84 | 78 | 65 | 75 |

| TIME    |    | db(A))(Sound Pressure Level |    |    |    |    |    |    |    |    |  |
|---------|----|-----------------------------|----|----|----|----|----|----|----|----|--|
| SEC MIN | 51 | 52                          | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |  |
| 5       | 69 | 78                          | 83 | 75 | 79 | 72 | 81 | 76 | 77 | 75 |  |
| 10      | 78 | 78                          | 75 | 78 | 70 | 67 | 78 | 79 | 78 | 74 |  |
| 15      | 82 | 85                          | 73 | 75 | 79 | 65 | 77 | 77 | 79 | 69 |  |
| 20      | 76 | 77                          | 81 | 77 | 75 | 75 | 78 | 69 | 85 | 71 |  |
| 25      | 72 | 78                          | 81 | 76 | 75 | 78 | 70 | 67 | 88 | 77 |  |
| 30      | 77 | 77                          | 83 | 79 | 75 | 79 | 69 | 71 | 78 | 74 |  |
| 35      | 78 | 77                          | 77 | 76 | 76 | 78 | 67 | 77 | 79 | 72 |  |
| 40      | 76 | 89                          | 76 | 67 | 77 | 75 | 74 | 75 | 77 | 78 |  |
| 45      | 78 | 77                          | 74 | 68 | 78 | 75 | 75 | 76 | 76 | 83 |  |
| 50      | 76 | 76                          | 70 | 76 | 74 | 84 | 81 | 74 | 77 | 74 |  |
| 55      | 75 | 74                          | 65 | 78 | 75 | 82 | 79 | 73 | 78 | 77 |  |
| 60      | 76 | 79                          | 76 | 74 | 75 | 73 | 78 | 76 | 77 | 75 |  |

## الخلاصة

تعتبر مقاومة الانزلاق من الخواص المهمة لسطح التبليط التي تؤخذ بنظر الاعتبار عند تصميم الخرسانة الإسفلتية والخرسانية ويجب أن تكون كافية لمنع انزلاق المركبات لضمان سلامة مستخدمي الطريق.

من الأهداف الرئيسية لهذا البحث دراسة العوامل المؤثرة على مقاومة الانزلاق من أجل السيطرة على المتغيرات واستخدامها في عملية التصميم بالشكل الذي يضمن توفر الأداء الأمثل لسطح التبليط ، فيما يتعلق بالتبليط الخرساني فقد تم دراسة تأثير المقاس الأقصى للركام (1"، 3/4"، 1/2")، نسب الخلط (1:1.5:3، 1:2:4، 1:3:6)، نوعية إنهاء السطح (خشن، ناعم)، نسب الماء إلى الاسمنت (0.45، 0.55، 0.65)، وحالة السطح (جاف، رطب)، أما التبليط الإسفلتي فقد تم شمول تأثير المقاس الأقصى للركام (1"، 1/2"، 3/4")، محتوى الإسفلت (4.1، 4.7، 5.3، 6.0)، حدود التدرج للركام، وحالة السطح (جاف، رطب) على أداء السطح في مقاومة الانزلاق.

لقد تم استخدام فحص البندول البريطاني لتقييم خشونة الدقيقة (Microtexture) والفحص الحجمي باستعمال الرمل لتقييم خشونة الأكبر (Macrotexture) بموجب أسلوب ASTM (E303) (E965) على التوالي. كما تم إجراء بعض الفحوصات الأساسية لتقييم الخلطات ومدى صلاحية استخدامها مثل فحص مقاومة الانضغاط ، فحص مقاومة الشد، فحص معامل المرونة للخلطات الخرسانية وفحص مارشال للخلطات الإسفلتية. أن زيادة معامل الانزلاق المطلوب لتوفير الأمان لمستخدمي الطريق قد يؤثر سلباً على زيادة استهلاك إطارات المركبات مع زيادة مستوى الضوضاء.

لدراسة الضوضاء تم اخذ ثلاث شوارع (اثنان تبليط أسفلتي و واحد تبليط خرساني) وتم بحث عوامل الحجم المروري ، سرعة المركبات ، كثافة ودرجة خشونة لسطح التبليط على مستوى الضوضاء باستخدام طريقة SPB و طريقة CPB ، وتبين من نتائج التجارب بان مستوى الضوضاء يزداد بمقدار 104% عند زيادة الحجم المروري للطريق من 1400 الى 1868 ويزداد بمقدار 118% عند زيادة سرعة المركبات من 20 إلى 50 كم \ساعة إما زيادة درجة خشونة سطح التبليط من 0.752 إلى 1.207 مم فان المستوي الضوضاء سيزداد بمقدار 105%.

إن نتائج الاختبارات على التبليط الخرساني تبين بان معايير الاحتكاك يزداد بمقدار 103% و 115% عند زيادة كل من المقاس الأقصى للركام في الخلطة من 1/2" الى 3/4" وباستخدام إنهاء خشن للسطح التبليط على التوالي بينما تزداد بمقدار 122% عند تقليل نسبة الماء إلى الاسمنت للخلطة من 0.55 إلى 0.45 . للخلطة الإسفلتية فان معايير الاحتكاك يزداد بمقدار 118% عند زيادة الحجم الأقصى للركام من 1/2" الى 3/4" ويقل بمقدار 93% عند زيادة المحتوى الإسفلتي للخلطة من 4.7 إلى 5.3 وان استخدام التدرج الخشن للخلطة الإسفلتية سيؤدي إلى زيادة مقاومة الانزلاق.

إن خلاصة النتائج تبين أن؛ المتغير الأكثر سيطرة على مقاومة الانزلاق في التبليط الإسفلتي هو المقاس الأقصى للركام و المتغيرات الأكثر سيطرة على مقاومة الانزلاق من التبليط الخرساني هي نسب الخلط و نوعية إنهاء السطح و نسب الماء إلى الاسمنت.



جمهورية العراق  
وزارة التعليم العالي والبحث العلمي  
جامعة بابل  
كلية الهندسة  
قسم الهندسة المدنية

# أداء سطح التبليط وعلاقته بخواص المواد

رسالة  
مقدمة إلى  
قسم الهندسة المدنية  
كلية الهندسة - جامعة بابل  
وهي جزء من متطلبات نيل شهادة ماجستير علوم في الهندسة المواصلات

من قبل:

سلام عادل مطلق

بإشراف:

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