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Temperature Zoning of Pakistan for Asphalt Mix Design

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Abstract

The current asphalt binder specifications in Pakistan are based on the Penetration Grade: penetration test is performed at 25°C. Penetration is an empirical measure of the consistency that is used as an empirical indicator of the rutting and fatigue susceptibility of asphalt binder, and is not related to pavement performance. The new mix design methodology developed under the Strategic Highway Research Program (SHRP), called the SUPERPAVE is a performance-based approach. The first step in the implementation of SUPERPAVE methodology is to establish high and low pavement temperatures for a location. The temperatures define the required Performance Grade (PG) of asphalt binder. This paper documents the initial ground work towards implementation of SUPERPAVE mix design for establishing high and low geographical temperature zones. The temperature zoning of Pakistan was carried out by using temperature data obtained from 64 weather stations. The SHRP and LTPP prediction models were utilized for predicting pavement temperatures. A significant difference was observed between the predicted pavement temperatures from both the models. The SHRP model gives higher, high temperature PG grade providing additional protection against rutting. Since rutting is the most common distress on flexible pavements in Pakistan, the SHRP models at 98% level of reliability is recommended. PG 70-10 binder seems to be the most common grade that encompasses more than 70% area of Pakistan. However, currently none of the two local refineries produce PG 70-10 binder, thus it should be a concern for the highway agencies. The polymer modified asphalt binder produced by Attock refinery (A-PMB) corresponds to harder PG 76-16 while A-60/70 (PG 58-22) or K-60/70 (PG 64-22) produced at Attock and National refineries respectively are softer compared to the PG 70-10. Harder grade is more prone to cracking, whereas softer grade of more prone to rutting. Consequently, the current construction practices which utilize A-60/70 or K-60/70 may be prone to excessive rutting.

Key Words: Superpave, Temperature Zoning, Performance Grade, Penetration Grade

1. Introduction

From October 1987 through March 1993, the Strategic Highway Research Program (SHRP) conducted a research effort to develop new ways to specify, test, and design asphalt materials [1]. The end result of SHRP asphalt research program is a development of a system referred to as SUPERPAVE, which stands for Superior Performing Asphalt Pavements. One of the key aspects of the SUPERPAVE is the development of the performance based binder specifications termed as Performance Grade (PG) asphalt. The major objective of the SHRP program was to relate mechanical properties of asphalt binder to field performance. Therefore, the new specification tests were developed to characterize asphalt binders at a broad range of temperatures and aging conditions. The three aging conditions specified are original, short term and long term aging. *Original* refers to virgin asphalt from the production plant; *short term* *aging* refers to properties at the time of production and placement of asphalt mix while *long term aging* refers to properties of asphalt binder during the service life of pavements. In addition to aging conditions, SUPERPAVE characterizes the asphalt binders at the actual pavement temperatures those are likely to experience. A brief summary of the binder grading systems for the purpose of mix design is given in the following section.

2.1 Binder Specifications

The development of binder testing goes back to 1888, when H. C. Bowen invented the Bowen Penetration Machine [2]. After several modifications of penetration equipment, by 1910 the penetration equipment became the standard for establishing the consistency of asphalt at 25°C. In 1918 the Bureau of Public Road (USA) introduced *penetration grading* system and by 1931 American Association of State Highway and Transportation Officials (AASHTO) published the standard specification to grade asphalt on penetration. The next major change in asphalt grading specification came with the introduction of *viscosity grading* system in early 1960s. Both ASTM and AASHTO adopted the viscosity grading system and provided grading specification by measuring the viscosity at 60°C.

Penetration grading system based on penetration of a standard needle under standard conditions in asphalt binder is empirical in nature. The empirical nature of test only provides the relative consistency of binder at specific temperatures, which can be used as an indicator of susceptibility of asphalt binder to rutting or cracking. However, it has performed quite satisfactorily for many decades in overcoming the major asphalt pavement distresses: permanent deformation and cracking (fatigue and thermal). ASTM D946 specified the five binder grades based upon penetration at 25°C. The greater the penetration the softer is the binder. In the case of viscosity grading, viscosity at 60°C (close to maximum pavement temperature) is specified. The specifications also require a minimum viscosity to be measured at 135°C to reduce the potential of tender mix at the time of compaction. ASTM D3381 specified six binder grades based upon the viscosity measured at 60°C. Table 1 provides the standard penetration and viscosity grades. The top row values in Table 1 represent relatively harder binders, whereas the lower rows represent the softer binder.

Table 1: Penetration and Viscosity Grading System

Penetration Grading		**Viscosity Grading**	
Grade	**Penetration in 0.1 mm**	**Grade**	**Viscosity @ 60°C, Poise**
Pen 40/50	40-50	AC-40	4000±800
Pen 60/70	60-70	AC-30	3000±600
Pen 85/100	85-100	AC-20	2000±400
Pen 120/150	120-150	AC-10	1000±200
Pen 200/300	200-300	AC-5	500±100
		AC-2.5	250±50

Generally, softer binder grades are used in the cold climates to resist cracking potential and harder binders for warmer climates to resist rutting potential. In Pakistan, a standard grade of Pen 60/70 is used for construction of flexible pavement. However, the refineries in Pakistan also produce Pen 40/50 and Pen 80/100. Viscosity grading is not yet established in Pakistan.

Viscosity grading system based on the fundamental property is considered a step forward in specifying the binder as compared to penetration grading. It require bidder to be tested at 60°C and 135°C, which corresponds to typical maximum pavement temperature and temperature at the time of mix production and placement in the field, respectively. Viscosity specification at 60°C helps in minimizing rutting potential, whereas, viscosity at 135°C aids to minimize the potential for tender mixes during paving operation. With all these added benefits, it fails to characterize the binder at low temperatures to minimize the potential of thermal cracking and pavement performance prediction. Figure 1 shows the criteria used for penetration and viscosity grading systems. It can be seen that two asphalt binders A and B meeting the penetration and viscosity specifications may behave very differently at other temperatures.

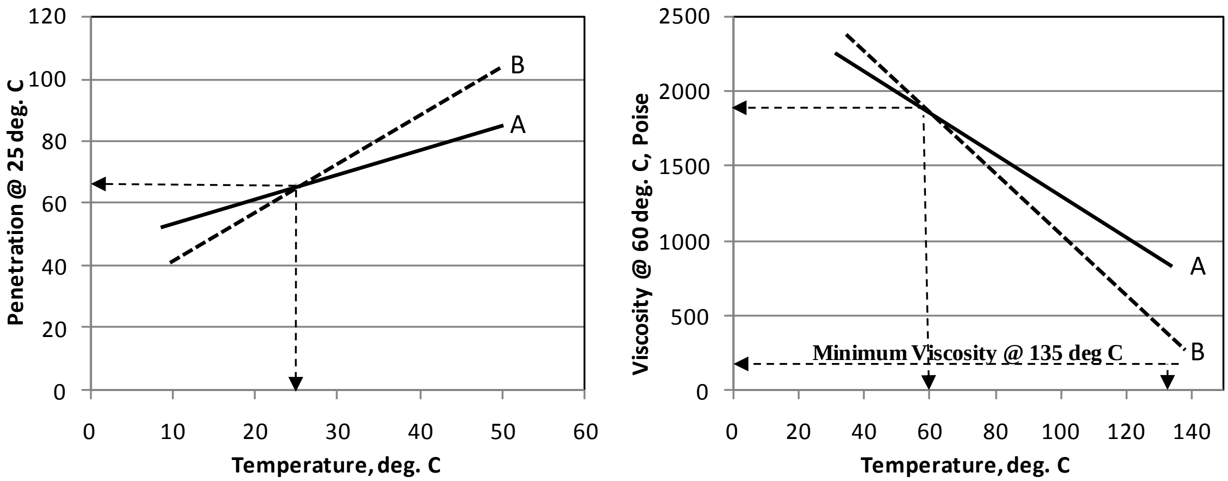


Figure 1: Graphical Comparison of two binders meeting Penetration and Viscosity Grading Specifications

The SUPERPAVE system is unique in a sense that asphalt binder is specified on the basis of the maximum and minimum pavement temperatures in which the binder is expected to serve. Mechanical properties requirement remain the same, but the temperature at which the asphalt binders achieve the physical properties corresponds to the pavement minimum and maximum temperature. For example, high temperature requires binder to have G*/sinδ to be at least 1.0 kPa for unaged condition (G* is the shear modulus in kPa and δ is the phase angle). The value of 1.0 kPa remains constant but the temperature at which this value has to be achieved depends upon the maximum pavement temperature. Another important feature of SUPERPAVE is that mechanical properties are measured on the asphalt binders at three conditions: unaged, short-term aged and long-term aged. The short and long-term aging is simulated in the laboratory using Rolling Thin Film Oven (RTFO) and Pressure Aging Vessel (PAV), respectively. The required mechanical properties at the three aging conditions both for high and low temperatures are specified in the SUPERPAVE specifications (MP1: Specification for Performance-Graded Asphalt Binder).

1.2 Temperature Grade

As mentioned earlier, binders are specified based on the temperature regime in which binder is expected to serve. The physical properties, such as the stiffness and shear modulus requirements are constant among all grades of binders. What differentiates the various binder grades is the temperature at which the requirements must be met. For example a binder classified as PG 64-22, means that the binder must meet the required properties least up to a maximum pavement temperature of 64^{o}C and down to a minimum pavement temperature of -22^{o}C. Table 2 presents the typical binder grades as is specified in the SUPERPAVE specifications. High temperature 46^{o}C have corresponding low temperatures of -34, -40, -46^{o}C; resulting in PG 46-34, PG 46-40 and PG 64-46. It is important to understand that PG grades are not limited to the ones given in Table 2. It is very possible to have PG 58-10, which is not included in Table 2.

Table 2: Binder Grades as Specified in SUPERPAVE Specifications *(1)*

High Temperature Grade, ^{o}C	Low Temperature Grade, ^{o}C
PG 46	34, 40, 46
PG 52	10, 16, 22, 28, 34, 40, 46
PG 58	16, 22, 28, 34, 40
PG 64	10, 16, 22, 28, 34, 40
PG 70	10, 16, 22, 28, 34, 40
PG 76	10, 16, 22, 28, 34
PG 82	10, 16, 22, 28, 34, 40

The temperatures given in Table 2 correspond to the pavement temperature and can be estimated from the air temperature data collected over the years. SUPERPAVE defines the high and low temperatures by 7-day average maximum air and l-day minimum air temperature. The 7-day average maximum temperature is defined as the average highest air temperature for a period of 7 consecutive days within a given year. The 1-day minimum temperature is defined as the lowest air temperature recorded in a given year. The data are collected over multiple years and the design high and low pavement temperature values are then estimated using the average and standard deviations of the data collected for a desired reliability level.

1.3 Pavement Temperature

Several research efforts have been carried out to relate the air temperature to pavement temperature. Regression equations along with mathematical heat flow theories have been used for the correlation. Among these, models for the prediction of high and low pavement temperatures based upon the air temperature data was established during the Strategic Highway Research Program (SHRP). However, later SHRP established the Long Term Pavement Performance (LTPP) program to support a broad range of pavement performance analysis leading to improved engineering tools to design, construct, and manage pavements. In this regards, the Seasonal Monitoring Program (SMP), a task of LTPP evaluated the effects of temperature variations on performance and validated the available models [3,4]. This resulted in a new set of pavement temperature prediction models for the high and low temperature grade. Given below are the models developed under the SHRP and LTPP program for high and low pavement temperature predictions.

High Temperature Models

The SHRP high temperature model was developed from the results of theoretical heat transfer modeling [5]. Based upon the data collected from several sites throughout the U.S. regression model was then developed for prediction of high pavement temperature as a function of depth. SUPERPAVE defines the high pavement design temperature at a depth of 20 mm below the pavement surface. Equation (1) represents model developed under the SHRP program, whereas Equation (2) is the LTPP model.

$$T_{pav,h} = (T_{air} - 0.00618\,Lat^2 + 0.2289\,Lat + 42.4)(0.9545) - 17.78 + z.\sigma_{air} \quad (1)$$

$$T_{pav,h} = 54.32 + 0.78T_{air} - 0.0025Lat^2 - 15.14\log_{10}(d+25) + z(9 + 0.61\,\sigma_{air}^2)^{1/2} \quad (2)$$

Where

$T_{pav,h}$	=	High AC pavement temperature at 20 mm from surface, °C.
$T_{pav,h,d}$	=	High AC pavement temperature at depth d from surface, °C.
T_{air}	=	High 7-day mean air temperature, °C.
Lat	=	Latitude of the section, degrees.
d	=	Pavement depth in mm,
σ_{air}	=	Standard deviation of the 7-day maximum air temperature, Deg. C
z	=	Standard normal dist. table, z = 2.055 for 98% reliability, and z = 0.0 for 50% reliability.

Low Temperature Models

SHRP considers the low air temperature as the design low pavement temperature [5]. The low pavement design temperature at the pavement surface is the same as the 1-day minimum temperature, since the air temperature is the same as the pavement surface temperature. This can be mathematically represented by the following relationship.

$$T_{pav,l} = T_{air} + 0.051x\,d - 0.000063x\,d^2 - z.\sigma_{air} \quad (3)$$

The LTPP low pavement temperature at the surface is presented in Equation (4) below.

$$T_{pav,l} = -1.56 + 0.72T_{air} - 0.004Lat^2 + 6.26\log_{10}(d+25) - z(4.4 + 0.52\,\sigma_{air}^2)^{1/2} \quad (4)$$

Where $T_{pav,l}$ = low AC pavement temperature in Deg. C

In the above equations (Equation 1 to 4), the factor "z and σ_{air}" is included to introduce reliability in the selection of binder grade. For example a high pavement temperature grade of 64 at 98% reliability level means that 98% of times the pavement temperature will not exceed 64^{o}C.

2. Temperature Data Base

In order to establish the Performance Grade (PG) for temperature conditions in Pakistan, temperature zoning for high and low pavement temperatures was carried as a first step. Using the above models, pavement temperature was estimated by making use of the air temperature data collected from the weather stations. In this regards, air temperature data from 64 weather stations across Pakistan was accumulated in a weather database created in Microsoft Excel Spreadsheet. These weather station locations covered almost all the geographical areas of the country. The air temperature data was collected from four main sources that included [6,7,8,9]:

1. Master's Thesis of Aurangzeb Qazi (National University of Science and Technology, 2008)
2. Pakistan Metrological Department
3. Weather Underground Web Site
4. Surface Water Hydrology Project, WAPDA Pakistan

Weather information for 21 stations for the years 1986-2006 was obtained from the work done by Qazi [6,7]. The database for the 21 stations was expanded for additional three years (2007 to 2009) using the "Weather Underground Web Site". The "Weather Underground" is a commercial weather service that provides weather information including temperature data via the Internet. Weather Underground website has information on major cities around the world on its web site [8]. Additional 43 weather stations were added using the information obtained from Surface Water Hydrology Project, WAPDA Pakistan [9] resulting in a total of 64 weather stations.

Table 3 summaries the weather stations used for the development of pavement temperature zoning. Table has information on the weather station, latitude,

Table 3: Summary of Weather Stations

No.	Station	Latitude (degrees)	Data Availability (years) (Low/High)[1]	No.	Station	Latitude (degrees)	Data Availability (years) (Low/High)[1]
1	Bagh	33.83	1986/1998-2007	33	Massan	33.00	1996-2007
2	Bahawal pur	29.03	2004-2009	34	Miani Forest	25.48	1996-2007
3	Bannu	33.00	1996-2007	35	Multan	30.20	1986/1996-2009
4	Besham Qila	34.93	1996-2007	36	Munda Dam	25.56	2000-2007
5	Chillya	24.83	1996-2007	37	Murree	33.92	1997/1996-2009
6	Chitral	35.85	1986/1996-2009	38	Nabisir	25.52	1996-2007
7	Daggar	34.50	1996-2007	39	Naran	34.90	1996-2007
8	Dainyor	35.92	1996-2007	40	Nokkundi	28.82	1986/1996-2009
9	Dalbandin	28.88	1997/1996-2009	41	Oghi	34.50	1996-2007
10	Domel	34.38	2005-2007	42	Panjgur	26.97	1997/1996-2009
11	Doyian	35.55	1996-2007	43	Parachinar	33.87	1986/1996-2009
12	Faisalabad	31.41	2004-2009	44	Pasni	25.25	2004-2009
13	Fort Lock	33.55	1996-2007	45	Peshawar	34.02	1986/1996-2009
14	Gilgit	35.92	1986/1996-2005	46	Phulra	34.33	1996-2007
15	Gujar Khan	33.25	1996-2007	47	Plandri	33.72	1996-2007
16	Gungi	34.34	2002-2007	48	Quetta	30.25	1986/1996-2005
17	Hub Dam	25.25	1996-2007	49	Rehman Bridge	33.48	1996-2007
18	Hyderabad	25.38	1986/1996-2005	50	Rohri	27.70	1997/1996-2009
19	Islamabad	33.62	1986/1996-2009	51	Sakrand	26.12	1996-2007
20	Jacobabad	28.28	2004-2009	52	Sargodha	32.08	2004-2009
21	Kachura	35.45	1996-2007	53	Sehwan	26.42	1996-2007
22	Kakul	34.18	1986/1996-2009	54	Shinkiari	34.47	1996-2007
23	Kala Bagh	32.95	1996-2007	55	Sialkot	32.52	2004-2009
24	Kalam	35.53	1996-2007	56	Sibbi	29.55	1986/1996-2005
25	Kallar	33.42	1996-2007	57	Skardu	35.30	1986/1996-2005
26	Kandia	33.87	2005-2007	58	Sukkur	27.69	2005-2009
27	Karachi	24.90	1986/1996-2009	59	Tank	32.22	2003-2006
28	Karim Abad	36.30	1996-2007	60	Tarbela	34.07	2002-2007
29	Khuzdar	27.83	1997/1996-2009	61	Thana Bula	25.37	1996-2007
30	Lahore	31.55	1986/1996-2008	62	Yugo	35.18	1996-2007
31	Mangla	33.13	1996-2007	63	Zhob	31.35	1986/1996-2009
32	Mardan	34.20	1996-2007	64	Zulam Br	26.97	2000-2006

Note: [1] 1986/1996-2009: low temperature data from 1986 to 2009 and high temperature data from 1996 to 2009.

Table 4: High and Low Air and Pavement Temperatures with PG Grading

No.	Location	High Air Temp. °C		Low Air Temp. °C		SHRP Models		LTPP Models		PG Grade @ 50% Reliability		PG Grade @ 98% Reliability	
		Avg.	Std. Dev	Avg.	Std. Dev	High Pavement Temp. °C	Low Pavement Temp. °C	High Pavement Temp. °C	Low Pavement Temp. °C	SHRP Model	LTPP Model	SHRP Model	LTPP Model
1	Bagh	35.0	3.1	-1.8	3.6	63.1	-9.2	61.6	-5.5	PG 58-10	PG 54-10	PG 64-10	PG 64-10
2	Bahawalpur	43.2	1.4	3.5	1.9	68.1	-0.4	67.4	1.2	PG 70-10	PG 64-10	PG 70-10	PG 70-10
3	Bannu	43.1	1.0	-1.7	2.0	66.6	-5.9	66.6	-3.7	PG 70-10	PG 64-10	PG 70-10	PG 70-10
4	Besham Qila	42.5	1.0	2.3	1.5	65.7	-0.7	65.7	-0.8	PG 64-10	PG 64-10	PG 70-10	PG 70-10
5	Chillya	39.7	1.5	8.1	2.9	65.5	2.2	65.3	4.5	PG 64-10	PG 64-10	PG 70-10	PG 70-10
6	Chitral	39.2	1.6	-5.4	2.0	63.6	-9.5	63.3	-7.0	PG 64-10	PG 58-10	PG 64-10	PG 64-10
7	Daggar	42.2	1.4	-3.8	1.7	66.5	-7.2	65.8	-5.3	PG 64-10	PG 64-10	PG 70-10	PG 70-10
8	Dainyor	41.1	1.6	-5.6	0.8	65.4	-7.2	64.8	-6.5	PG 64-10	PG 64-10	PG 70-10	PG 70-10
9	Dalbandin	46.2	1.0	-5.1	2.4	70.4	-10.1	69.7	-5.4	PG 70-10	PG 64-10	PG 76-10	PG 70-10
10	Domel	39.1	2.8	0.0	0.6	66.3	-1.2	64.5	-2.0	PG 64-10	PG 58-10	PG 70-10	PG 70-10
11	Doyian	40.1	1.4	-1.4	1.1	64.2	-3.6	64.0	-3.5	PG 64-10	PG 58-10	PG 70-10	PG 64-10
12	Faisalabad	41.5	2.3	2.8	1.3	68.2	0.2	66.5	0.5	PG 64-10	PG 64-10	PG 70-10	PG 70-10
13	Fort Lock	29.4	1.7	-4.8	1.5	54.8	-8.0	56.1	-5.7	PG 52-10	PG 52-10	PG 58-10	PG 58-10
14	Gilgit	41.2	1.5	-7.7	1.2	65.4	-10.2	64.8	-8.2	PG 64-10	PG 64-10	PG 70-10	PG 70-10
15	Gujar Khan	41.5	2.1	-1.8	1.2	67.3	-4.3	65.9	-3.2	PG 64-10	PG 64-10	PG 70-10	PG 70-10
16	Gungi	35.3	1.6	-3.3	2.3	60.1	-7.9	60.5	-5.3	PG 58-10	PG 58-10	PG 64-10	PG 64-10
17	HubDam	40.5	2.0	8.7	1.6	67.2	5.5	66.2	6.0	PG 64-10	PG 64-10	PG 70-10	PG 70-10
18	Hyderabad	41.4	1.2	6.5	1.4	66.5	3.5	66.5	4.5	PG 64-10	PG 64-10	PG 70-10	PG 70-10
19	Islamabad	41.0	2.5	-0.2	1.0	67.7	-2.2	65.8	-2.0	PG 64-10	PG 64-10	PG 70-10	PG 70-10
20	Jacobabad	46.2	2.3	5.3	3.2	72.8	-1.3	70.4	1.4	PG 70-10	PG 64-10	PG 76-10	PG 76-10
21	Kachur	35.4	1.9	-10.2	2.1	60.7	-14.5	60.7	-10.5	PG 58-10	PG 58-10	PG 70-16	PG 64-10
22	Kakul	35.4	2.5	-2.8	2.0	62.2	-6.9	61.3	-4.7	PG 58-10	PG 58-10	PG 64-10	PG 64-10
23	Kalabagh	44.7	1.0	0.0	0.9	68.4	-1.8	67.9	-1.7	PG 70-10	PG 64-10	PG 70-10	PG 70-10
24	Kalam	30.4	2.3	-11.7	1.8	56.8	-15.3	57.0	-11.3	PG 54-16	PG 54-10	PG 58-16	PG 58-16
25	Kallar	40.9	1.0	2.9	1.2	64.4	0.4	64.7	0.2	PG 64-10	PG 58-10	PG 70-10	PG 64-10
26	Kandia	39.1	3.2	-3.2	3.1	67.2	-9.6	64.9	-6.0	PG 64-10	PG 58-10	PG 70-10	PG 70-10
27	Karachi	37.2	1.2	5.5	3.1	62.5	-0.9	63.2	2.3	PG 64-10	PG 58-10	PG 64-10	PG 64-10
28	Karimabad	34.7	1.7	-6.0	1.5	59.5	-9.2	59.8	-7.3	PG 58-10	PG 58-10	PG 64-10	PG 64-10
29	Khuzdar	40.3	1.2	-1.0	2.4	65.0	-5.8	65.2	-2.1	PG 64-10	PG 64-10	PG 70-10	PG 70-10
30	Lahore	41.4	2.0	3.2	2.4	67.3	-1.8	66.1	-0.1	PG 64-10	PG 64-10	PG 70-10	PG 70-10
31	Mangla	42.5	1.3	1.7	0.9	66.8	-0.2	66.2	-0.5	PG 64-10	PG 64-10	PG 70-10	PG 70-10
32	Mardan	42.9	0.7	-2.2	1.0	65.7	-4.3	66.1	-3.6	PG 70-10	PG 64-10	PG 70-10	PG 70-10
33	Massan	45.0	1.6	2.1	1.6	69.8	-1.2	68.3	-0.6	PG 70-10	PG 64-10	PG 70-10	PG 70-10
34	Miani Forest	44.1	3.4	5.5	3.9	73.5	-2.5	70.3	1.4	PG 70-10	PG 64-10	PG 76-10	PG 76-10
35	Multan	43.8	1.5	2.0	1.1	68.7	-0.3	67.8	0.4	PG 70-10	PG 64-10	PG 70-10	PG 70-10
36	Munda Dam	42.4	1.1	4.2	0.7	67.2	2.8	67.2	3.2	PG 70-10	PG 64-10	PG 70-10	PG 70-10
37	Murree	27.9	2.2	-6.8	3.0	54.4	-12.9	55.2	-8.5	PG 52-10	PG 52-10	PG 58-16	PG 58-10
38	Nabi Sar	43.4	1.7	4.4	1.1	69.3	2.2	68.2	3.2	PG 70-10	PG 64-10	PG 70-10	PG 70-10
39	Naran	28.2	3.4	-14.6	1.5	57.1	-17.7	56.5	-13.0	PG 52-16	PG 52-10	PG 58-22	PG 58-16
40	Nokkundi	46.0	1.1	-3.1	1.6	70.4	-6.3	69.5	-3.3	PG 70-10	PG 64-10	PG 76-10	PG 70-10
41	Oghi	36.3	2.5	-1.5	1.1	63.0	-3.7	62.0	-3.2	PG 58-10	PG 58-10	PG 64-10	PG 64-10
42	Panjgur	42.3	1.0	-2.2	2.1	66.7	-6.5	66.8	-2.6	PG 70-10	PG 64-10	PG 70-10	PG 70-10
43	Parahinar	33.8	1.5	-9.7	3.3	58.6	-16.5	59.4	-10.9	PG 58-10	PG 58-10	PG 58-16	PG 64-16
44	Pasni	37.1	1.8	9.0	2.7	63.6	3.4	63.5	5.2	PG 64-10	PG 58-10	PG 64-10	PG 64-10
45	Peshawar	42.3	2.1	1.0	1.4	68.0	-1.9	66.4	-1.5	PG 64-10	PG 64-10	PG 70-10	PG 70-10
46	Phulra	41.2	1.4	-3.4	1.0	65.5	-5.5	65.0	-4.6	PG 64-10	PG 64-10	PG 70-10	PG 70-10
47	Plandri	35.4	1.2	-0.8	0.8	59.6	-2.3	60.5	-2.4	PG 58-10	PG 58-10	PG 64-10	PG 64-10
48	Quetta	39.5	1.2	-9.3	1.8	64.1	-12.9	64.3	-8.2	PG 64-10	PG 58-10	PG 70-16	PG 70-10
49	Rehmab Br.	41.0	1.2	1.3	1.2	64.9	-1.1	64.9	-1.1	PG 64-10	PG 58-10	PG 70-10	PG 70-10
50	Rohri	45.4	1.5	4.1	1.4	70.5	1.2	69.3	2.3	PG 70-10	PG 64-10	PG 76-10	PG 70-10
51	Sakrand	44.4	3.0	7.0	3.1	73.0	0.7	70.1	3.2	PG 70-10	PG 64-10	PG 76-10	PG 76-10
52	Sargodha	42.5	3.1	4.0	3.5	70.5	-3.1	67.8	-0.7	PG 70-10	PG 64-10	PG 76-10	PG 70-10
53	Sehwan	48.2	1.0	5.8	1.4	72.3	2.9	71.5	3.8	PG 76-10	PG 70-10	PG 76-10	PG 76-10
54	Shinkiari	37.9	1.1	-1.0	0.7	61.6	-2.5	62.3	-2.7	PG 64-10	PG 58-10	PG 64-10	PG 64-10
55	Sialkot	41.4	2.6	1.8	1.0	68.3	-0.2	66.3	-0.3	PG 64-10	PG 64-10	PG 70-10	PG 70-10
56	Sibbi	47.6	1.9	2.3	1.3	73.3	-0.4	71.1	0.6	PG 70-10	PG 70-10	PG 76-10	PG 76-10
57	Skardu	36.5	2.5	-14.3	4.5	63.0	-23.5	62.0	-16.0	PG 58-16	PG 58-10	PG 64-28	PG 64-16
58	Sukkar	41.6	2.6	2.0	2.6	69.3	-3.4	67.3	-0.3	PG 64-10	PG 64-10	PG 70-10	PG 70-10
59	Tank	47.0	2.7	1.7	2.9	73.9	-4.3	70.9	-1.8	PG 70-10	PG 64-10	PG 76-10	PG 76-10
60	Tarbela	44.3	1.3	3.2	1.3	68.1	0.6	67.4	0.1	PG 70-10	PG 64-10	PG 70-10	PG 70-10
61	Thana Bulla	44.5	0.9	3.5	1.7	68.8	-0.1	68.7	2.1	PG 70-10	PG 64-10	PG 70-10	PG 70-10
62	Yugo	33.4	1.8	-9.9	1.2	58.6	-12.3	59.1	-9.6	PG 58-10	PG 58-10	PG 64-16	PG 64-10
63	Zhob	39.6	1.0	-1.0	2.4	63.7	-5.8	64.1	-3.0	PG 64-10	PG 58-10	PG 64-10	PG 70-10
64	Zulam Br.	39.6	1.7	-1.4	3.0	65.7	-7.6	65.1	-2.9	PG 64-10	PG 64-10	PG 70-10	PG 70-10

and number of years of data used for the analysis. Data collected for each station was used to estimate the yearly high and low air temperatures values based 7-day maximum average and the minimum air temperature. The yearly high and low temperature data were then used for the computation of average and standard deviation values required for computing pavement temperatures. Pavement high and low temperatures were estimated using both SHRP and LTPP models (Equations 1 to 4). Table 4 gives the summary of pavement temperature data used for estimating the PG requirements at 50% and 98% level of reliability. In addition to the PG grade information, table also summarizes the statistical parameters, average and standard deviation for each weather station.

It was observed that the temperatures in Pakistan vary significantly from one end of the country to another, with northern part much cooler compared to southern part. The lowest air temperature observed is -14.6^{o}C and the high 7-day average air temperature in excess of 48^{o}C. From the data given in Table 4, range of air temperature at any given location may be from 28^{o}C to 51^{o}C. However, the corresponding range of pavement temperature is between 60^{o}C to 87^{o}C at 98% level of reliability using the SHRP models.

3. Temperature Data Analysis

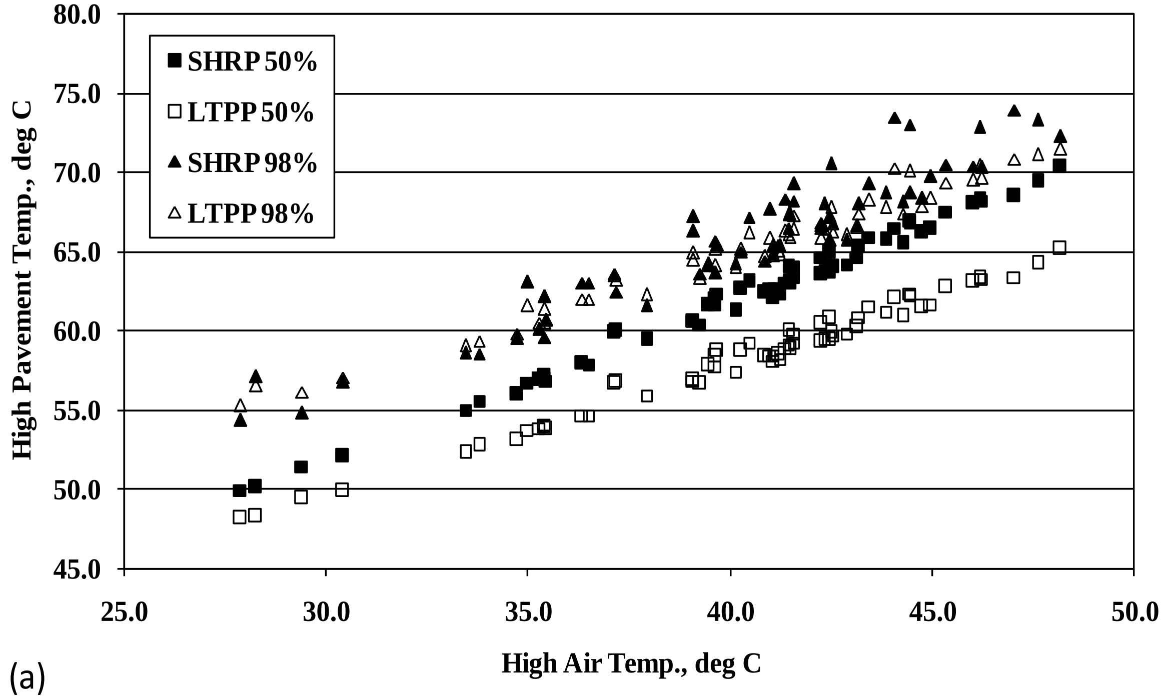
From the air temperature data, pavement temperatures are predicted using the SHRP and LTPP approaches. A comparison of the predicted pavement temperatures from two models is presented in Table 5. The results show the statistical comparison for the low and high pavement temperature data at 98 percent level of reliability for all the 64 sites.

No significant difference was observed for high pavement temperature predictions using the SHRP and LTPP approach at 98% level of reliability in terms of the average and standard deviation values. However, low pavement temperature showed more variability in prediction using the SHRP and the LTPP models. The predicted low pavement temperature using SHRP model is lower as compared to the LTPP model for the same air temperature data. The SHRP models provide additional protection against low temperature cracking as compared to LTPP models.

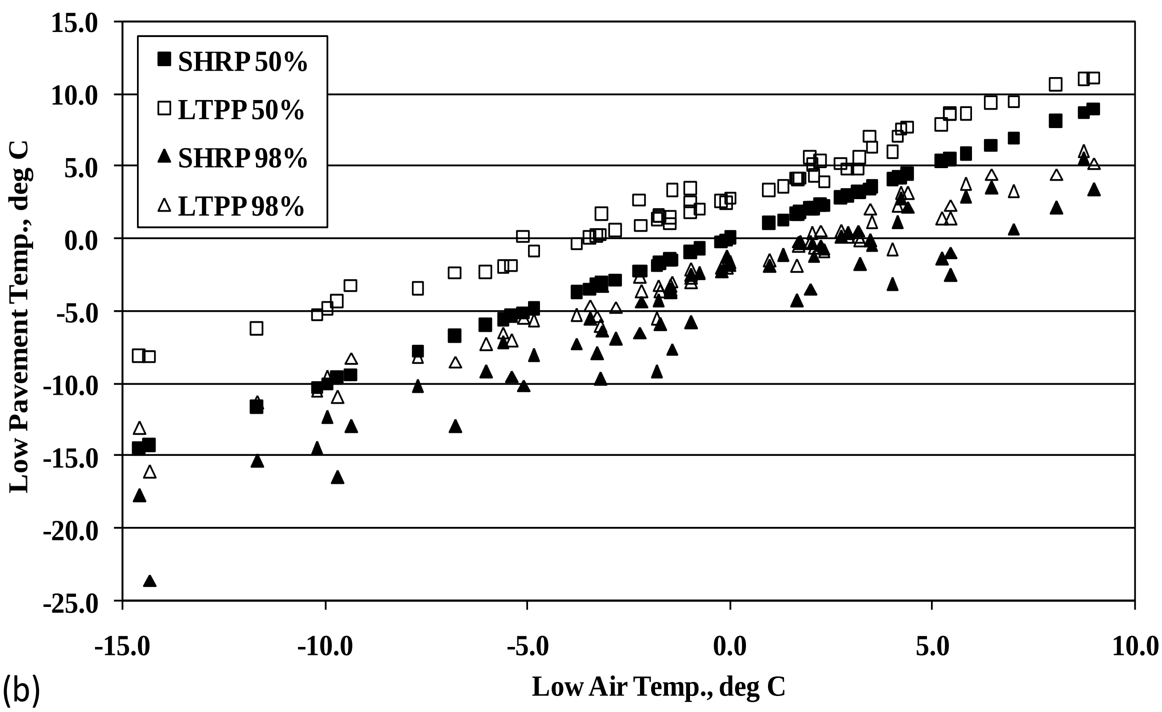
Figure 2 shows the predictive high and low pavement temperature predictions as a function of air temperature for the 64 sites. Figure 3 presents the same data in the form of a histogram. Significant differences were observed in pavement temperature predictions using both the models with the SHRP model predicting a much lower temperature values compared to the LTPP model. A paired student t-test was carried out to compare the results of the SHRP and the LTPP models both for 7-days high average and 1-day low pavement temperatures. The results of the paired t-test are summarized in Table 6. Values of *t-statistics*, t-critical and the probability of null hypothesis being true (*p-value*) are summarized for four cases. In all situations, the absolute value of *t-statistics* is greater than *t-critical*, i.e. because the probability of null hypothesis being true is very small (close to zero) suggest that significant difference exists between the predictions of pavement temperature from the two models. Therefore, the null-hypothesis that there is no statistical difference is rejected.

Table 5: Comparison of SHRP and LTPP Predictions

Statistical Parameter	SHRP Models		LTPP Models	
	High Temperature	Low Temperature	High Temperature	Low Temperature
Minimum Temp. deg. C	54.4	-23.5	55.2	-16.0
Maximum Temp. deg. C	73.9	55	71.5	6.0
Average, deg. C	65.7	-4.5	65.1	-2.5
Standard Deviation, deg. C	4.5	5.8	3.7	4.6
Coefficient of Variation (%)	6.8	-128.4	5.8	-181.0

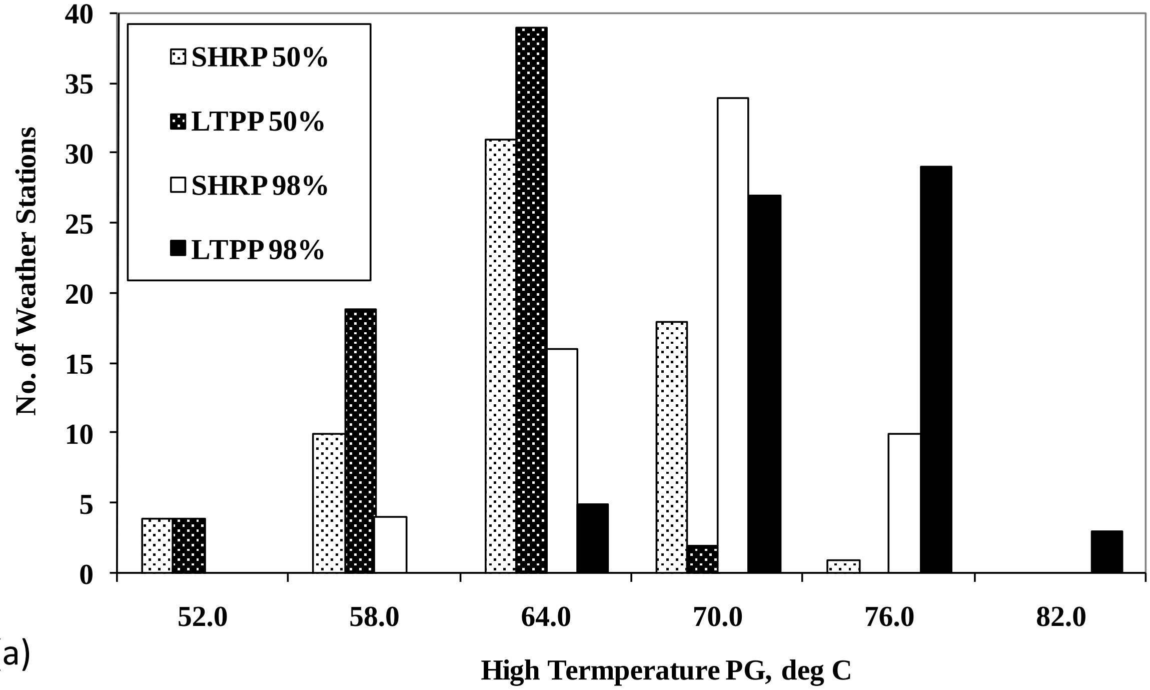


(a)

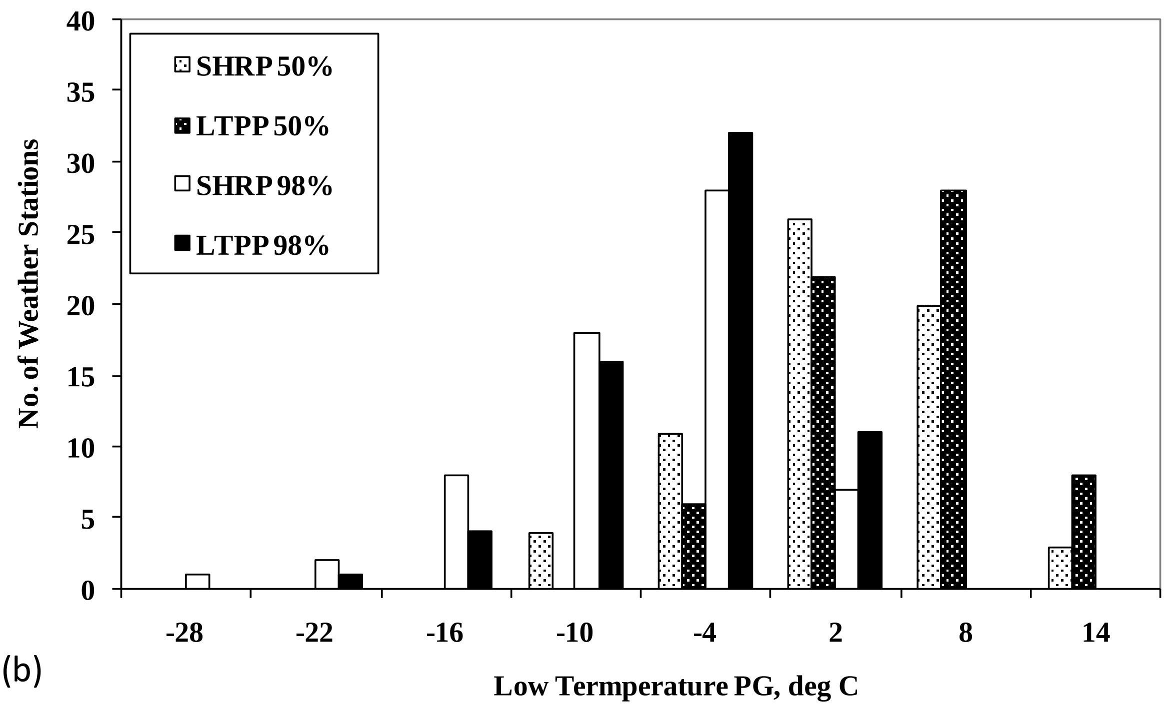


(b)

Figure 2 High and Low Pavement Temperatures as a Function of Air Temperature



(a)



(b)

Figure 3 Histogram of High/Low Pavement Temperatures for 64 Stations

Table 6: Paired t-Test Comparison of SHRP and LTPP Models

Pavement Temp. Condition	Reliability Level (%)	Average Pavement Temperature, deg. C		t Stat	t Critical two-tail	P(T<=t) two-tail
		SHRP	LTPP			
High	50	61.90	58.20	37.55	2.00	0.00
	98	65.55	69.72	35.46	2.00	0.00
Low	50	-0.76	2.64	23.81	2.00	0.00
	98	-4.60	-2.60	8.99	2.00	0.00

4. Temperature Zoning And Pg System

Based on the information collected from 64 weather stations, 7-days average high and low pavement temperatures were estimated for 50% and 98% level of reliability using SHRP and LTPP models (Equations 1 to 4). Table 4 presents PG grading for each weather station for SHRP and LTPP models for 50% and 98% reliability levels.

As mentioned earlier, significant differences in the prediction of pavement temperatures were observed using both the models with SHRP models being more severe compared to LTPP models. When considering the conditions in Pakistan, most parts of Pakistan experiences moderate to high temperatures. The most common distress is rutting as a result of high temperature and uncontrolled traffic loads. Low temperature cracking is not common because temperatures below -10^{o}C are not very common and may be observed only on a limited scale. Because of the above mentioned facts of high temperatures and uncontrolled traffic loading, it was decided to use SHRP models for the purpose of temperature zoning. SHRP models in general require higher Performance Grade (PG) and thus provide extra protection against high temperatures. Since most the traffic on the national highways have uncontrolled axle loading, it is important that the final required grades be based on 98% level of reliability.

Figure 4 shows the PG temperature zoning across Pakistan based on SHRP models for 98% level of reliability. It can be observed that most part of Pakistan falls in PG 70 - 10 category with PG 64-10 in the second place. PG 58-22 is only required for a limited area in northern part of Pakistan.

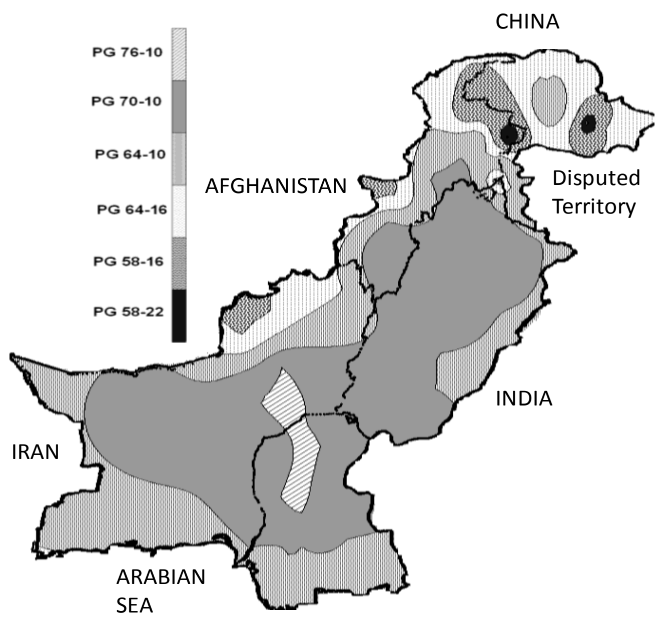


Figure 4: Temperature Zoning for PG System in Pakistan [10]

The Attock and Karachi are the two major refineries in Pakistan each refinery producing three types of binder grades which are specified based on the penetration grading system. As a part of Pak-US Cooperative Research Program (10), available binders were graded based on the penetration, viscosity and PG system and are summarized in Table 7.

As shown in Figure 4, the entire area is divided into six grades depending upon the temperature zoning. A summary of these grades is provided in Table 8 as required PG grade (column 1). The second column has the grades that are available, whereas third column list the combination of grades that fulfill requirement specified in column. That is PG 64-16, satisfies the requirements of PG 64-10 according to AASHTO MP1. Under the remarks column, all binders are considered acceptable except for PG 70-10. That is PG 76-16 satisfies the requirement of PG 70-16, but may result in harder binder which may not be desirable and prone to cracking. In addition, PG 76-16 (A-PMB) is polymer modified asphalt, which is relatively more expensive compared to neat (unmodified) asphalt.

PG 70-10 which is the requirement for more than 70 percent of Pakistan is not produced by any of the two refineries. This is considered to be one of the most important grade requirements.

Table 7: Summary of Binder Grading for Asphalts in Pakistan

Sr. No.	Refinery	Binder	Penetration Grade	Viscosity Grade	PG Grades of Available Asphalts in Pakistan
1	Attock	A-PMB	Not Available	AC-40	PG 76-16
2	Attock	A-60/70	Pen 60/70	AC-20	PG 58-22
3	Attock	A-80/100	Pen 60/70	AC-10	PG 58-22
4	Karachi	K-40/50	Pen 40/50	AC-40	PG 64-16
5	Karachi	K-60/70	Pen 60/70	AC-20	PG 64-22
6	Karachi	K-80/100	Pen 85/100	AC-10	PG 58-22

Note: "A" for Attock Refinery and "K" for Karachi Refinery

Table 8: Summary of Binder Grading for Asphalts in Pakistan

Required PG Grade	**Available Exact Grade**	**Possible Grade Availability**	**Equivalent Penetration Grade**	**Remarks**
PG 70-10	No	PG 76-16	A–PMB	PMB, Polymer Modified may be too hard for PG 70-10 and may result in cracking
PG 64-10	No	PG 64-16	K–40/50	Acceptable
PG 64-16	Yes	PG 64-16 PG 64-22	K–40/50 K–60/70	Acceptable
PG 58-16	No	PG 58-22	K–80/100 A–80/100 A–60/70	Acceptable
PG 76-10	No	PG 76-16	A–PMB	Acceptable
PG 58-22	Yes	PG 58-22	K–80/100 A–80/100 A–60/70	Acceptable

5. Observations And Conclusions

The main objective of the paper is to divide Pakistan into temperature zones according to the PG requirements developed under SHRP. Several observation and conclusions are briefly presented below:

The two model forms, SHRP and LTPP for the prediction of pavement temperatures resulted into significantly different predictions both for high and low temperatures. However, relatively greater differences were observed for low temperature compared to high temperature predictions.

SHRP prediction models for high and low temperatures were selected for the development of PG zones for Pakistan, since SHRP requires higher grade requirement for the high temperature grade, which is critical for uncontrolled axle loading.

The use of 98% level of reliability provides additional safety margin against high traffic levels and uncontrolled loadings. No additional bumping of grade is needed as is recommended by AASHTO MP1 specifications, since it will result in excessively stiff binder.

Pakistan is divided into six temperatures zones requiring PG 70-10 as the most important binder that covers more than 70 percent of the area.

PG 70-10 is not produced by any of the two refineries in Pakistan. The closest grade that fulfills the requirements of PG 70-10 is PG 76-16 (A-PMB). A-PMB is relatively harder and may prone to cracking. Use of PG 64-16 is relatively softer than the required grade and may prone to rutting.

At present, commonly used grade in Pakistan is A-60/70 and K-60/70. The corresponding grades are PG 58-22 and PG 64-22 which is likely to rut in areas requiring PG 70-10. This may be one of the major reasons of premature failures especially rutting in most of our pavements.

6. Acknowledgement

The authors acknowledge the Pakistan-United States Science and Technology Cooperative Program for funding this research.

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