PERFORMANCE EVALUATION OF POLYMER MODIFIED BITUMEN IN FLEXIBLE PAVEMENTS

Final Year Project UG 2014

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This is to certify that the

Final Year Project, titled

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LIST OF ACRONYMS

AASHTO – American Association of State Highway and Transportation Officials

AC – Asphalt Concrete

ARL – Attock Refinery Limited

ASTM – American Society for Testing and Materials

HMA – Hot Mix Asphalt

ITFT – Indirect Tensile Fatigue Test

ITS – Indirect Tensile Strength

NHA – National Highway Authority

OBC – Optimum Bitumen Content

UTM – Universal Testing Machine

VA – Air Voids

VFA – Voids Filled with Asphalt

VMA – Voids in Mineral Aggregate

PMB – Polymer Modified Bitumen

PVC – Polyvinyl Chloride

TSR – Tensile Strength Ratio

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ABSTRACT

Transportation facilities and infrastructure play a vital role for the purpose of interconnectivity. For the design of these facilities all the highway design agencies look for appropriate, long lasting and cost effective techniques. To achieve these objectives it was intended to incorporate plastic (PVC) replacing bitumen in the asphalt mix.

PVC's products are widely used around the globe. There is no sustainable method to recycle PVC waste. When burnt dioxins are produced which are detrimental for human health. When added to landfill they pose a threat to leach into the ground and contaminate ground water.

The performance of pavement over time period reduces because of fatigue and moisture. Therefore such a design is ideal which is cost effective and environment friendly. The project is based on performance evaluation of asphalt mixes using different percentages of PVC replacing bitumen and comparing the properties of polymer modified bitumen with virgin bitumen. NHA gradation B, ARL grade 60/70 and PVC obtained from Gujrat were used in this study. Penetration, ductility and temperature testing was carried out on virgin bitumen and bitumen replaced by different percentage of PVC. i.e.: 3%, 6%, and 9%. Optimum Bitumen Content (OBC) and Optimum Modifier Content (OMC) was determined followed by performance testing. Using OBC and 3% replacement of bitumen by PVC, various samples were prepared and tested for evaluation and their performance results were then compared.

CHAPTER 1

INTRODUCTION

Background:

The increasing demand for plastics in the world leads to pressures on the environment generated by the consumption of raw materials based on fossil fuels and the need for plastic waste reduction and absorption to diminish their environmental impacts. PVC is an incredibly versatile material used in bottles, packaging, toys, construction materials, bedding, clothing, piping, wire coatings, imitation leather, furnishings and more. Globally, PVC is at third rank in plastic output and production. 39.3 million Tons of PVC were consumed globally in 2013 and this figure is increasing annually. Since PVC is not biodegradable or degradable. This means that when waste plastics are dumped they did not deteriorate hence affecting the lives of living things. The issue of plastic pollution along Pakistan's coast line is a major concern and is worsening due to an adequate waste disposal system in the city. Pakistan being one of the populous countries in the world is facing problems because of lack of waste management infrastructure.

Problem Statement:

Flexile Pavements are vulnerable to Fatigue Cracking, Moisture Damage, Stripping, Rutting, etc. during the first few years of its service life. Bitumen is the most expensive material in Hot Mix Asphalt (HMA) and its reduction in quantity in HMA mix will be beneficial. Use of plastics in the construction of pavements using replacement method without compromising overall pavement performance would reduce overall cost as well.

Purpose of Research

Growing production and usage of PVC products asks for their proper processing and treatment. In Pakistan most of the plastics don't get properly disposed and it could lead to alarming health related issues. The study to use plastics has undergone in many countries including Bangladesh, India, and Australia but in Pakistan there hasn't been a significant research on the effects of adding plastics to the bitumen. There has been a boom in the transportation infrastructure of Pakistan under the current government especially because of the economic corridor between neighboring countries Pakistan and China. The project involves construction of 1200 KM long motorway between Lahore and Karachi, widening and overhauling of Karakoram Highway from Rawalpindi to China. In addition, many projects regarding roadways are in process including metro bus service project, Orange line train project. If adding plastic could enhance the properties of roads in Pakistan so this is the golden hour to employ plastic in road. As Pakistan is already among the countries whose climate is being adversely affected by the environment so this becomes an ideal time for conducting this study because it would enhance cost effectiveness and have a positive impact on the environment.

Research Objective

The chief objective is to replace bitumen with PVC in Asphalt Mixes. The objectives are listed as

- Fatigue evaluation of virgin bitumen and polymer modified bitumen and their comparison.
- Moisture susceptibility of virgin and polymer modified bitumen and their comparison.
- Cost effective construction of roadways.
- To achieve all these goals without compromising the performance of pavement.
- Utilizing optimum percentage of PVC without affecting the overall pavement performance.

Organization of report

Chapter 1: It discusses the problems linked with the generation of PVC and its probable usage in pavement, problems relating to usage, problem statement and research objective.

Chapter 2: Literature Review.

Chapter 3: Entails methodology adopted to carry out the project which includes procurement, characterization of materials in laboratory, Marshall Mix Design and Performance Testing.

Chapter 4: Extends the results of performance testing and their analysis.

Chapter 5: Abridges the conclusions of laboratory testing and discusses future recommendations.

CHAPTER 2

LITERATURE REVIEW

Introduction

This chapter will cover the literature & theory related to need of transportation, several methods being used to design flexible pavements. An overview to plastics, waste plastics & its impact on the environment, former studies related to the plastic used in pavement & their results. The Fatigue and Moisture Susceptibility test on asphalt mixes are discussed in detail.

Need of transportation

An efficient transportation system plays a vital role in country's economy. A large number of people in our country travel by means of road on daily basis. Currently, Pakistan is having a very poor public transportation system in many major cities, as Pakistan Railway is not fully functional according to the demand of public due to time delays, lesser number of locomotives available & less connectivity among the cities. Due to this, a huge number of individuals prefer to travel by road using their own vehicles. Developed countries like UK, USA, Korea, Japan, & China have efficient transport communications between different locations. Good transportation system helps in the development of country, not only this but it also increases the country's economy.

Currently, the situation is getting improved. Pakistan in collaboration with China is constructing a new trade route called CPEC (China Pakistan Economic Corridor) to connect Gwadar port with Kashgar (City of China) .Several Motorways & highways are being constructed & still its expansion is in progress. Around 3690 km of motorway is being constructed in various regions of nation. A large portion of this will be functional by 2019. Public transport system is also improving under this project, Orange-line train service in Lahore & Metro service in 3 different cities i.e.: Islamabad, Lahore & Multan are good examples of transportation revolution in Pakistan. Metro bus service in Peshawar & Karachi are being constructed & they will be operational soon to meet the requirements of public. In CPEC project, Karachi & Lahore will be connected by 1100 km long motorway, the main railway line between Karachi & Peshawar will also be upgraded by December 2019.

Flexible Pavements

Flexible pavement is composed of a bituminous material surface course and underlying base and subbase courses. The bituminous material is more often Asphalt whose viscous nature allows significant plastic deformation. Most Asphalt surfaces are built on a gravel base, although some full depth Asphalt surfaces are built directly on subgrade. Depending on the temperature at which it is applied, Asphalt is categorized as Hot Mix Asphalt (HMA), warm mix Asphalt or cold mix Asphalt. Flexible pavement is so named as the pavement surface reflects the total deflection of all subsequent layers due to traffic load acting upon it. The flexible pavement design is based on the load distributing characteristics of a layered system.

It transmits load to the subgrade through a combination of layers. Flexible pavement distributes load over a relatively smaller area of the subgrade beneath. The initial installation cost of a flexible pavement is quite low which is why this type of payment is more commonly seen universally. However, the flexible pavement requires maintenance and routine repairs every few years. In addition, flexible pavement deteriorates rapidly, cracks and potholes are likely to appear due to poor drainage and heavy vehicular traffic.

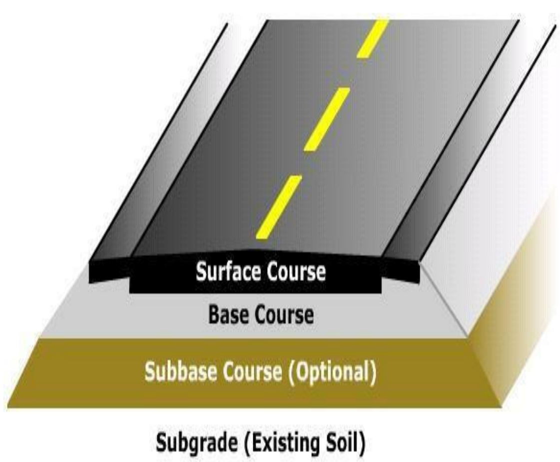


Figure 2.1: Typical cross section of the layered system in conventional Flexible pavement

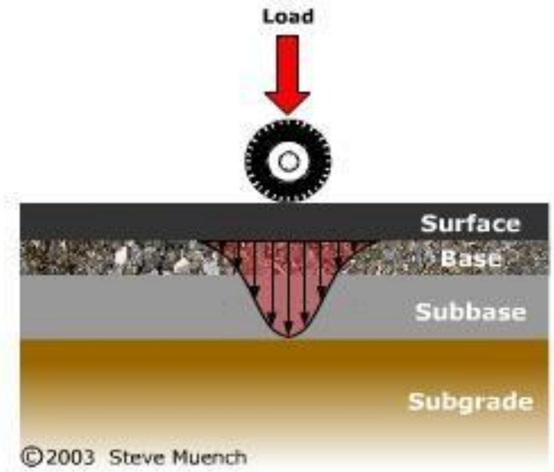


Figure 2.2: Load Distribution in Flexible Pavement

Design Methods

Two methods are used for the design of Flexible pavements which include

- Marshall Mix Design
- Super pave Mix Design

Marshal Mix Design

This method of flexible pavement design was first developed by Bruce Marshal in 1939 and then modified by US Army. It is one of the most popular and cheaper method use. This method focuses on the determination of optimum bitumen content (OBC) for different blend of aggregate used. It also encounters traffic level in the design of pavement.

For the determination of OBC samples are prepared for different asphalt content generally in the range of 3.5 % to 6% of total sample weight. 3 samples are prepared for each asphalt content. After that following tests are performed on these samples.

- Bulk density determination
- Stability and flow test
- Density and void analysis

Five different curves are plotted versus asphalt content at x-axis.

The optimum bitumen content for the mix design is determined by taking average value of the following three bitumen contents found form the graphs obtained in the previous step.

Bitumen content corresponding to maximum stability

1. Bitumen content corresponding to maximum bulk specific gravity (G_m)
2. Bitumen content corresponding to the median of designed limits of percent air voids (V_v) in the total mix (i.e. 4%)

Super Pave Mix Design

This method was designed to replace the Marshall methods (Strategic Highway Research Program (SHRP)). The volumetric analysis done in the Marshall methods provides the basis for the super pave mix design method. The Super pave method helps in designing a pavement that is tailored to the performance requirements at a site dictated by the traffic, climate, the environment etc. tying asphalt binder and aggregate selection into the mix design process. The process helps in selection of an OBC and combining it aggregates or any modifier necessary to achieve the required level of performance. The compaction devices from the Marshall procedure have been replaced by a gyratory compactor and the compaction effort in mix design is tied to expected traffic.

The Objective of this design system is to define an economical blend of bitumen and aggregate that yields a paving mix having

- Sufficient bitumen content
- Sufficient (VMA) and air voids, (Va)
- Workability and satisfactory performance characteristics over the entire service life of the pavement.

The super pave mix design method consists of 7 basic steps:

- Aggregate selection.
- Asphalt binder selection.
- Sample preparation (including compaction)
- Performance Tests

- Density and voids calculations
- Optimum asphalt binder content selection.
- Moisture susceptibility evaluation

The super pave gyratory compactor establishes three different gyration numbers specified by the super pave volumetric mixture design

1. Initial number of gyrations ($N_{initial}$), It is used as a measure compaction of the mixture during construction. If $N_{initial}$ are too low the mixture compacts too quickly and may turn out to be unstable when it is subjected to traffic

   N_{design}, this is the design number of gyrations required so that the sample has the same density as that it would have in the field after the indicated amount of traffic produce a sample with the same density as that expected in the field after the indicated amount of traffic. A mix with 4 percent air voids at N_{design} is desired in mix design.

2. N_{max}, the maximum number of gyrations required to produce a density in the laboratory that should never be exceeded in the field. If the air voids at N_{max} are too low, potential rutting can occur as the field mixture may compact too much under traffic.

The OBC corresponds to that asphalt content which result in 4% air voids at $N_{design.}$ This OBC should also meet other criteria mentioned below.

- Air voids at initial number of gyration should be greater than 11%
- Air voids at maximum number of gyrations should be greater than 2%.
- VMA and VFA should also fall within the given range.

Plastics

Plastic is a material consisting of any of a wide range of synthetic or semi-synthetic organic compounds that are malleable and so can be molded into solid objects. Plasticity is the general property of all materials which can deform irreversibly without breaking but, in the class of moldable polymers, this occurs to such a degree that their actual name derives from this specific ability.

Plastics are typically organic polymers of high molecular mass and often contain other substances. They are usually synthetic, most commonly derived from petrochemicals, however, an array of variants are made from renewable materials such as polylactic acid from corn or cellulosic from cotton linters.

Due to their low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in a multitude of products of different scale, including paper clips and spacecraft. They have prevailed over traditional materials, such as wood, stone, leather, metal, glass, and ceramic

Polyvinyl Chloride (PVC)

PVC is the world's third-most widely produced synthetic plastic polymer, after polyethylene and polypropylene. PVC comes in two basic forms: rigid (sometimes abbreviated as RPVC) and flexible. The rigid form of PVC is used in construction for pipe and in profile applications such as doors and windows. It is also used in making bottles, non-food packaging, and cards (such as bank or membership cards). It can be made softer and more flexible by the addition of plasticizers, the most widely used being phthalates. In this form, it is also used in plumbing, electrical cable insulation, imitation leather, signage, phonograph records, inflatable products, and many applications where it replaces rubber.

Some of the most significant properties of Polyvinyl Chloride (PVC) are:

1. Density: PVC is very dense compared to most plastics (specific gravity around 1.4)
2. Economics: PVC is readily available and cheap.
3. Hardness: Rigid PVC is very hard.
4. Strength: Rigid PVC has extremely good tensile strength.

Polyvinyl Chloride is a “thermoplastic” (as opposed to “thermoset”) material which has to do with the way the plastic responds to heat. Thermoplastic materials become liquid at their melting point (a range for PVC between the very low 100 degrees Celsius and higher values like 260 degrees Celsius depending on the additives). A major useful attribute about thermoplastics is that they can be heated to their melting point, cooled, and reheated again without significant degradation.

Advantages of Polyvinyl Chloride

1. Polyvinyl Chloride is readily available and relatively inexpensive.
2. Polyvinyl Chloride is very dense and thus very hard and resists impact deformation very well relative to other plastics.
3. Polyvinyl Chloride has very good tensile strength.
4. Polyvinyl Chloride is very resistant to chemicals and alkalies.

Impacts of plastics on Environment

Rapid increase in population also increased the demand of different products being used by people on daily basis which are often made up of plastics e.g.: plastic bottles, kitchenware, packing materials etc. Ultimately, increasing the waste production & most of the waste products contain plastics such as PVC, Polyethylene & others, which are normally non-biodegradable & harmful to the environment. Once we dispose the waste material, their burning produces harmful gases such as Carbon monoxide, Nitrogen oxide and Sulphur oxides which are hazardous for both humans & animals. By taking this into account, we must avoid the open burning of these waste plastics in the environment to protect ourselves. Moreover, these waste plastics can be recycled and used to form new products.

Not only have these waste plastics contaminated river and ocean water, causing serious problem to marine lives. In order to control all this, we should recycle and use it as a polymer in road construction to enhance the properties of asphalt binder

Use in Pakistan

Use of PVC has increased tremendously in Pakistan. The main problem associated with waste PVC is its slow rate of decomposition as it takes hundreds of years to decompose and as long as it remains in the environment, it causes serious impact on daily routine and also on environment. These waste plastics have serious impact on nature as usual practice is to dispose it off and their burning produces Carbon dioxide, Carbon monoxide which are contributing to global warming. Unlike other developing countries where PVC demand exploded due to rapid increase in use of PVC pipes in Construction and Agriculture industries, utilization of PVC pipes of high standards in these sectors has yet to take roots in Pakistan.

Previous work

Bituminous concrete is used for road surfacing, airports, parking lots etc. It is a blend of asphalt and aggregate mixed together to achieve better performance.

Unfortunately, roads in Pakistan deteriorate before time because of improper design, increase of traffic, poor drainage & insufficient degree of maintenance due to lack of funds available and interest of governing body. To avoid all these issues, effective measures must be taken i.e.: sufficient funds must be secured for maintenance, good quality of material must be used, and roadway design must be according to the AASHTO standards & adopt better construction methods.

All around the world, waste plastics are causing much pollution to the surrounding environment. So, the whole world is interested in using the plastics for some beneficial purpose. One of our objectives in this project is to replace some percentage of bitumen with PVC to get some beneficial use of plastics.

Problem Statement

Temperature, overloading, permanent deformation & inadequate cross-slopes are the various factors for failure of Hot Mix Asphalt (HMA) pavements. Polymer modified asphalt concrete have been developed in recent years to address the pavement performance issues but taking into consideration the traffic loads as well. Several waste materials from manufacturing industries and households, increase in growth rate of population has increased the industries production of various types of waste materials like: blast furnace, slag, plastic, etc. To solve this problem, recycling of waste products must be practiced.

This research focusses on determining Optimum Modifier Content% that can replace bitumen in HMA so as not affecting the performance of pavement and likewise fulfilling the reuse of waste products.

Literature Review

Several research works have been carried out to check performance of pavement by adding different percentages of plastics including PVC and Polyethylene (LDPE). Work has been started 25 years back (Haberl 1980). Some important research work that discussed the use of polymer in HMA include: Md. Nobinur Rahman 2013; M. S. Ranadive 2012; Sangita 2011; Ho and Zanzooto 1994; Fawcett and McNal-ly 2000 and Sami-ud-din 2017.

Previous studies recommended that 10% Polyethylene and 7.5% PVC by weight of bitumen can be used for bituminous roads for the view point of stability, stiffness and void characteristic. But these recommended values are for 80/100 penetration grade bitumen. It was also suggested that 10% of bitumen can be replaced by plastic waste in bituminous layer. Cost reduction in bitumen is nearly about 8% when the bitumen is replaced by 10% plastic waste. Moreover, the addition of waste plastic modifier in bituminous road construction also increases the volume of total mix as the plastic modifier is added as an extra item to the whole mix, thus contributing much more strength and service life to the roads.

Moisture Susceptibility

Moisture Susceptibility is the damage caused by water to asphaltic pavement by reducing strength of bond between the binder and aggregate. It has become a serious concern for the Asphaltic Pavement performance (HUNTER 2001).

The low compaction temperature while producing HMA is known to be causing inadequate drying of aggregate leading to susceptibility to moisture induced damage (HURLEY 2006).

Moisture susceptibility is related to the presence of air voids which gets filled with moisture causing damage to pavements. Two types of moisture induced failure are commonly related.

Cohesive failure related to reduced bond strength of binder and Adhesive failure between binder and aggregate. (ZOLLINGER, 2005).

Moisture Susceptibility can be termed as loss in durability and strength of Asphalt Pavement and is due to interaction of moisture with fine aggregate and binder if there is a problem of bonding between the two. Less the bonding between aggregate and binder, more is the potential for moisture induced damage (AHMED, 2014).

Moisture Susceptibility result in gradual loss of strength over time which may result in Stripping, the phenomena in which aggregate is detached from asphalt cement, leading to development of rutting and shoving in the wheel paths. Therefore, it is necessary to determine that whether the pavement designed is capable to resist damage from moisture presence.

Procedures for Evaluating Moisture Susceptibility

Moisture induced stress Test (MIST) simulates the field conditions. It exposes the HMA specimen to repeated pore pressures as experienced by the pavement on field due to repeated tire load. It is basically an assembly consisting of a compressor to load air and a vacuum to load air in and out of the HMA specimen.

Determining the Dynamic Modulus can aid in evaluating the moisture susceptibility of HMA mix as Dynamic modulus is the indicator of viscosity of Mix. Determining Dynamic modulus before and after the condition of Mix can be handy to check the Tensile strength ratio of HMA sample.

Moisture Damage can also be evaluated from Hamburg wheel-tracking device. Several different factors influenced the result from this device. Several studies were done to list down the factors affecting the results from Hamburg device. These were identified as quality of aggregate, asphalt cement stiffness, long and short term aging of asphalt cement, the properties of crude oil from which asphalt was extracted, compaction temperature.

Zhao, et al. (2013) proposed consideration of contact angle measurement and dynamic modulus results to reinforce the conventional test method of Moisture Susceptibility, which proved to valuable in recent findings.

Determination of Surface energy was employed by ZOLLINGER in evaluating the Moisture Susceptibility. Universal Sorption device and Wilhelmy plate were employed to measure surface energy from aggregate and binder. Possible Problematic combinations of aggregate and binder were identified from the ratio of adhesive bond energy under wet conditions to adhesive bond energy under dry conditions.

ZOLLINGER also employed dynamic mechanical analyzer to determine moisture susceptibility. The ratio of number of cycles to failure of wet specimen to number of cycles to failure of dry specimen was employed to evaluate the moisture damage of pavement.

McCann, et al. evaluated moisture damages by applying accelerated moisture conditioning. In this method, a loose mix specimen is kept in water bath at 60 °C while subjecting it to ultrasonic energy. To quantify moisture damage, the percent material lost from specimen is recorded for five hours and plotted against conditioning time. The slope of the curve is a measure of moisture damage to pavement.

Indirect tensile Strength test (ITS) can be useful for Performance testing of pavement. Moisture Damage can be evaluated by this method by determining the Tensile strength of pavement both conditioned and unconditioned. It consists of loading the Specimen diametrically until cracking, the more the peak value of loading the more the strength of pavement.

In 1998, Maine Dot recommended of determining Tensile Strength Ratio (TSR) of conditioned sample to a unconditioned sample as most appropriate measure of moisture damage to pavement (Washington State Department of Transportation, 2009). This method can be more acceptable by consideration of contact angle measurement and dynamic modulus results (TAO & MALLICK, 2008).

The procedure used in this research is based on ALDOT 361-88 which determines Tensile Strength Ratio of conditioned sample to unconditioned sample. The conditioning of sample is done in water bath at 60 °C for 24 hours after which it is placed for another 1 hour at 25 °C. The unconditioned sample is placed at 25 °C for 1 hour. The TSR ratio should be minimum 80% for satisfactory performance of road.

Fatigue Cracking

Theory

Fatigue cracking in flexible pavement refers to phenomena of formation of interconnected cracks in asphalt pavement due to application of repeated loading. As per Pell, P.S., 1971 fatigue cracking is fracture of material under repeating or fluctuating having maximum value generally less than the strength of material.

Initially it was assumed that fatigue cracking only result because of wheel loads but as more researches were made the definition was extended to include temperature variation and construction practices. It was further revealed that cracking consists of two phases, crack initiation and crack propagation.

Many researches highlighted the need of understanding the crack mechanism in asphaltic pavement which leads to fatigue cracking. Many factors like temperature, loading rate, and aging of bitumen were identified to have links with fatigue cracking.

Fatigue cracking reduces the life of pavement. The magnitude, frequency of load application, and the duration of load application was later identified to have major effect on pavement performance. (MONISMITH, 1985)

The asphaltic pavement at high temperature is not capable to maintain its original shape and leads to a phenomenon of rutting while at low temperature it is brittle (AASHTO 2002).

Test Methods

Different methods are being used to check the fatigue life of asphaltic pavement. The difference among most of them is the mode of loading applied. These methods classified according to mode of load application are as under:

- Simple flexure
- Direct axial loading
- Diametric loading

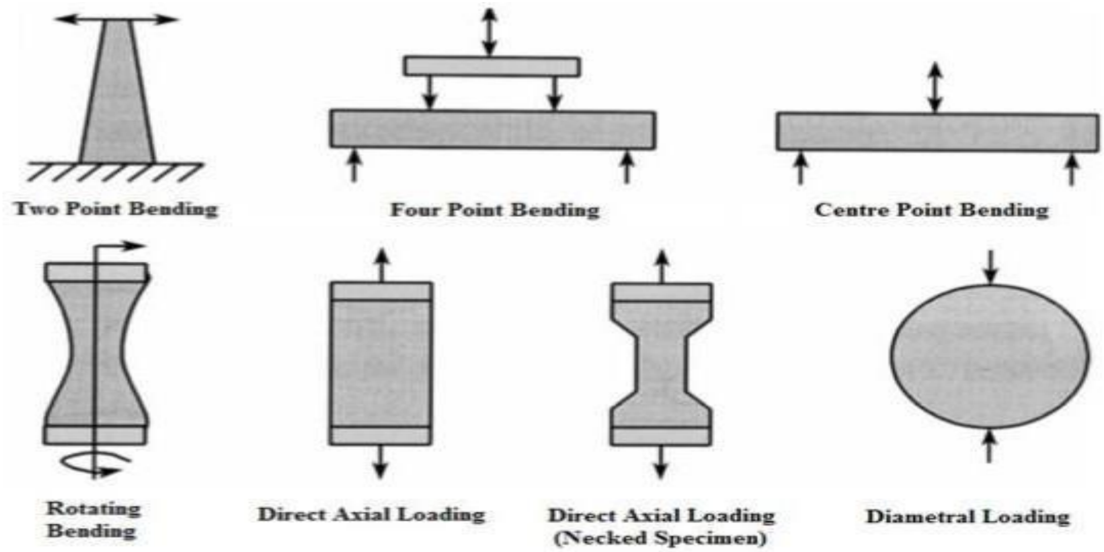


Figure 2.3: Test Methods for determining Fatigue life

Simple flexure test consists of Centre point bending, two-point bending, four- point bending. Whereas direct axial loading consists of cylindrical and necked cylindrical specimen in tension and compression under axial load. And diametric loading is applied along the diameter of specimen.

The three test methods are described below with respect to their advantages and disadvantages.

Simple Flexural:

Simple flexural method is widely used. It can be used for evaluation of pavement as well as well pavement material. The result obtained can be directly used to estimate the fatigue resistance of pavement. It can be used for stress controlled design of thick pavement and strain controlled design of thin pavement.

While coming to its disadvantages it requires much more time for test. The equipment used is also of specialized type which makes it costlier. Moreover, the results are inadequate for pavement having thickness between 50mm and 150mm.

Direct Axial:

This test method is less costly as compared to simple flexural. It takes less time to finish the test procedure. Stresses and strain in tension mode can be easily measured. Simple cylindrical specimen is required so no need to fabricate the sample.

Although very simple and cheaper test but the problem associated with this test is its correlation with field conditions so stresses and strains measured from this test doesn't correspond to actual field stresses and strains.

Diametric Loading:

This test is easiest way of determining the fatigue life of pavement. The equipment used can also be used to perform another performance test like ITS test. Field core can also be tested through this method. Fewer specimens are required to reach a conclusion as this test method has less variability coefficient as compared to other test methods.

The fatigue life determined from this test varies widely as determined by other tests. Stress distribution at point of loading does not simulate the field conditions. Permanent deformation of specimen occurs which is not allowed in flexure.

Factors Affecting Fatigue

Fatigue is dependent on the mode of loading, loading pattern and rest period, stresses induced in pavement and mixture variable.

Mode of loading

Two types of loading is generally used for fatigue test depending on the pavement thickness namely stress controlled and strain controlled.

When the pavement has lesser thickness, strain controlled mode of loading is used as these types of pavement experience tensile strain at bottom of pavement and leads to tensile cracks further loading will increase the cracks propagation. The load applied in this method is reduced.

When the pavement is thick, cracks generally appears at the top of pavement surface due to tire pavement interaction. In stress controlled mode of loading stress is kept constant while strain increases.

As more research was done on mode of loading Monismith and Salam in 1979 deduced that.

- When pavement thickness is less than 50mm then strain controlled mode of loading represent its characteristics.
- When pavement thickness is greater than 150 mm stress controlled mode of loading is the best representation of it.

Between 50 to 150 mm thicknesses some intermediate loading need to be considered.

Load waveform

The Load waveform have direct effect on the fatigue life of HMA pavement, more the energy applied in one cycle of loading the less will be the fatigue life (Irwin 1977).

The frequency and duration of wave form has also significant effect on fatigue life. By decreasing the duration & keeping frequency constant increases fatigue life. The haversine waveform simulates the field conditions efficiently.

The increased fatigue life due to decreased duration is related to healing of cracks in pavement. As more time, will be available between load applications more time will be available for healing of cracks therefore more fatigue life. After conducting different field experiments, around 5 seconds to 25 seconds was recommended to be rest period between load applications.

Mixture variables

The factors defining the fatigue life of pavement are primarily the bitumen content, its stiffness and air voids present in pavement. Apart from this aggregate type, its gradation used also effect fatigue life up to some extent. The angularity, gradation of aggregate effect on fatigue is related to bitumen content utilized according to these properties of aggregates.

- **Bitumen Content**
  - The bitumen content present in mix have a direct effect on the fatigue life of pavement. Generally more the bitumen content more will be the fatigue life of pavement but the bitumen used must be within the limits as more the bitumen used will increase rutting of pavement resulting in less durability of pavement.

- **Bitumen stiffness**

  More the stiff the bitumen is more will be the fatigue life of pavement in stress controlled conditions (Cooper and Pell 1974). While more stiff the bitumen less will be the fatigue life in case of strain controlled conditions. (Epps and Monismith 1971). Work has been done on using 50 grade bitumen instead of 100 grade bitumen at university of Nottingham Brown et al, 1982. The result showed that there was considerable increase in fatigue life that could compensate reduced thickness of pavement.

Indirect tensile fatigue test

The indirect tensile test is easy to perform and estimate the fatigue life of a pavement. The specimen to be tested is easy to prepare. The fatigue life of pavement measured from ITFT is generally less than other methods. (Kennedy et al., 1975).

The loading applied produces vertical compressive stress and horizontal tensile stress along the diameter of specimen. Stress is maximum at the center, the strain can be calculated by assuming that material is homogenous, force is line loading & there are plane stress conditions.

The advantages of ITFT is its simplicity, the equipment can be used for other test also, field cored specimen can also be tested, there is less variability in results for same type of mix.

The disadvantage is that fatigue life is underestimated as it is determined by tensile stresses. It leads to permanent deformation. Stiffness is not reliably measured as that from trapezoid or beam test.

In ITFT load can be varied while it can be performed across various temperatures as well. The maximum number of cycles to failure is the fatigue life of pavement.

The stress at the center of pavement can be calculated by the formula

$$\sigma = \frac{2000P}{\pi t D}$$

Whereas strain by

$$\varepsilon = [\left(\frac{2\Delta H}{D}\right) \times \left(\frac{1+3v}{4+\pi * v-\pi}\right)]$$

Where:

σ = Tensile stress at the center of specimen (Kpa) ε = Tensile strain at the center of specimen

P = Maximum load (Newton) t = Specimen height (mm)

D = Specimen diameter (mm) ΔH = Horizontal deformation

Summary

In this chapter, firstly we discussed the needs and benefits of transportation system for any country, how it plays a role in the development of any country's economy by giving examples of developed nations like: UK, USA, Korea, China and Japan. After that, an overview regarding the design of flexible pavements, their methods i.e.: Marshall and Superpaver were discussed. Plastics, its uses and impacts on environment were then discussed briefly that how it causes pollution to our environment. Many researches in the past have used plastics in pavement and have found satisfactory results. Their recommendations were briefly analyzed and discussed. After that, a review was given on different test methods used for determining fatigue life and moisture susceptibility of pavement. ALDOT 361-88 is the most widely used method for determining moisture susceptibility. Factors affecting fatigue life of a pavement were then discussed. Methods used to determine fatigue life were also discussed. The advantages and disadvantages of indirect tensile fatigue test over other test methods were discussed briefly.

CHAPTER 3

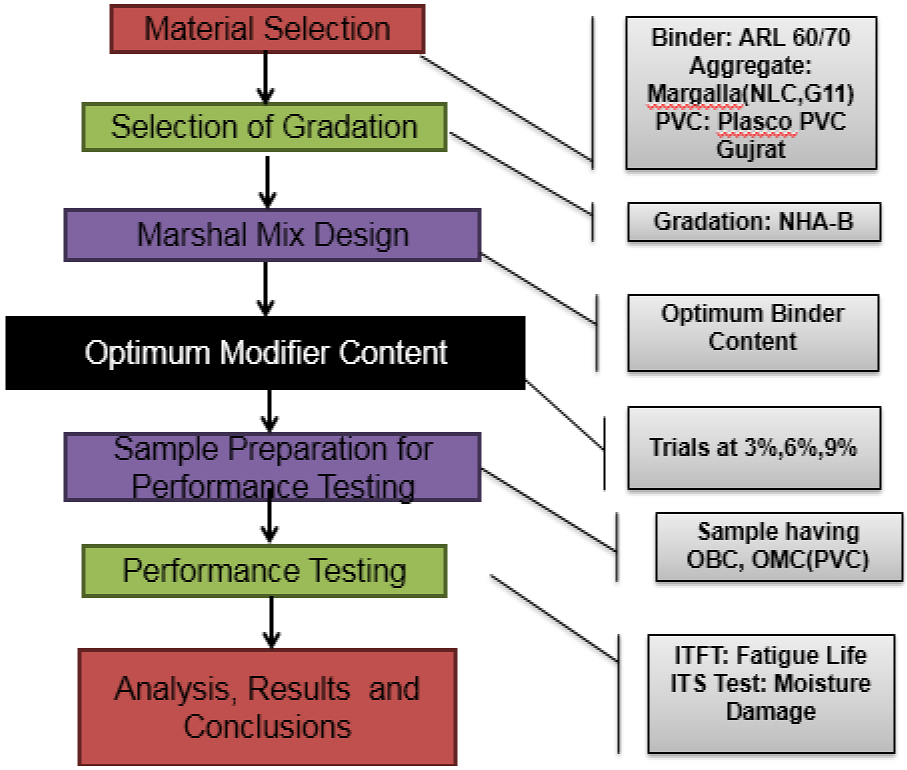
RESEARCH AND TESTING METHODOLOGY

Introduction:

This chapter focuses on the methodology followed to achieve the aims and objectives of the study which includes material acquisition, testing of material, specimen preparation and various tests on specimen. The study was carried out on conventional mix as well as sample containing PVC. In this chapter, determination of OBC of virgin bitumen & determination of Optimum Modifier Content using different percentages of PVC (3%, 6% & 9%) in asphalt is discussed. Based on the OBC samples for performance testing will be prepared with and without addition of PVC, the percentage of PVC being used is 3% of bitumen. Performance testing includes Moisture Susceptibility and Fatigue testing. The equipment used, the procedure used for the preparation of samples, along with the input parameters used during testing on the specimen prepared will be discussed in this chapter.

Research Methodology:

Aggregate was of Margalla hills crush plant site collected from NLC Camp Site G-11, after that PVC was collected from Plasco Pipes (pvt.) Ltd. These materials were brought to laboratory of NATIONAL INSTITUTE OF TRANSPORTATION (NIT) and several tests were conducted on aggregate and tests on Asphalt were also conducted. Asphalt was procured from NIT Lab which was of Attock Refinery Limited. After that Marshall specimen were prepared for finding OBC of virgin bitumen. These OBC's were then used to prepare samples to perform Performance test on samples containing PVC.



Material Collection

Aggregate:

Aggregate was of Margalla hills crush plant site collected from NLC Camp Site G-11. Aggregate plays a vital role in defining the strength, durability of pavements. The properties of aggregate that are related to strength are greatly influenced by the texture and shape of the aggregate material. Generally, more angular and rough textured the aggregate is more It is capable to resist stresses in pavement due to application of repeated loads. Several tests are performed as per ASTM and BS to check properties of aggregate affecting pavement

Bitumen:

In Pakistan, mostly bitumen of grade 60/70 is utilized as per weather conditions. So bitumen of grade 60/70 was collected from NIT lab which was initially obtained from Attock Oil Refinery (ARL).

PVC:

These plastics were collected from Plasco Pipes Industries (pvt.) Ltd., Gujrat. These were used to replace a part of OBC obtained from Marshall Sample. This composite bitumen, having bitumen and PVC, was then used to prepare samples for performance testing.

Material Testing

Aggregate Tests:

Aggregate offers resistance to deformations in pavements so it should have sufficient strength, texture so that it can withstand repetitive loads on pavement. Following tests were performed on aggregate.

- Shape Test.
- Specific Gravity and Water absorption test.
- Impact value of Aggregate.
- Los Angles Abrasion Test.

Three samples were prepared for each test and their result were compiled in the table below.

Shape test of Aggregate (ASTM D 4791-99):

This test determines the percentage of flaky and elongated particles in aggregate. Flaky particles are defined to be those having their least dimension lesser then 0.6 times their mean dimension. While elongated particles are defined to be those having their greatest dimension greater than 1.8 times their mean dimension. For better interlocking of aggregate particles angular shape is preferred. The flakiness index should be less than 15% while elongation index less than 15%.

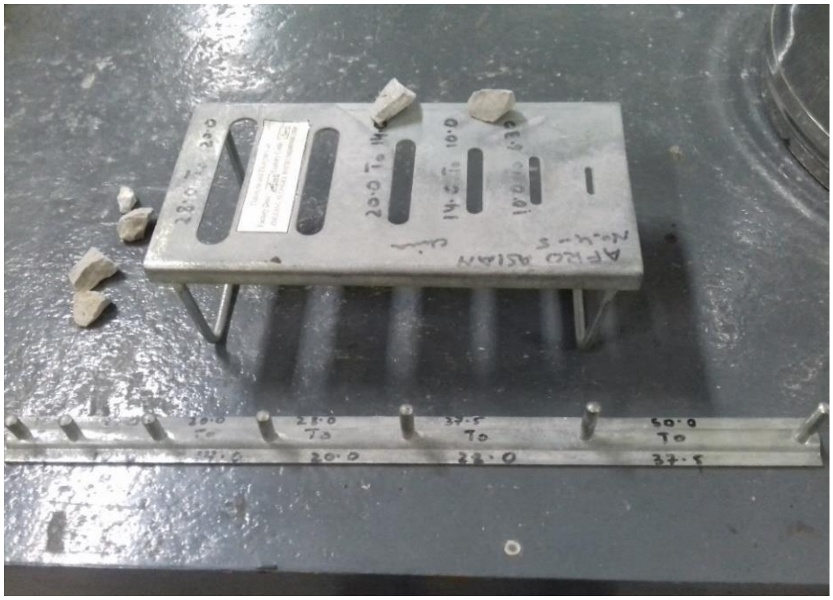


Figure 3.1: Shape Test Apparatus

Specific Gravity Test (ASTM C 127 & ASTM C 128):

Specific gravity is the ratio of weight of given volume of aggregate to weight of equal volume of water at 23 °C. This test was performed only on coarse aggregate per ASTM C 127-88. Three weights were determined for calculating Specific gravity i.e. weight of oven dried aggregate, weight of aggregate completely submerged in water, and Saturated surface dry weight of aggregate. Specific Gravity of Fine aggregate and water absorption was determined using ASTM C 128.

Figure 3.2: Buoyancy Balance

Impact Value of Aggregate (BS 812):

The impact value of aggregate gives its relative strength against impact loading. The equipment required was impact testing machine, temping rod, sieves of sizes 1/2”, 3/8” and #8 (2.36mm). About 350 grams of sample passing sieve ½” and retained on 3/8” was transferred impact testing machine cup in three layer while each layer was temped 25 times with the help of temping rod. After that it was subjected to 25 blows from rammer of impact machine weighing 14 kg and free fall of 38 cm. After that material was taken out from cup and passed through sieve #8. The

Figure 3.3: Impact Value Test Apparatus

percent passing through sieve #8 gives impact value of aggregate. The results are summarized in table below.

Los Angles Abrasion Test (ASTM C 131):

This test is used to check resistance of aggregate to wear and tear due to heavy traffic load. More the abrasion value of aggregate more the performance of pavement is adversely affected. The equipment used was LOS angles machines, sieve set, balance steel balls. NHA Gradation B was selected for this test. About 5000g of sample, containing 2500g retained on sieve ½" and 2500g retained on 3/8", was placed in Los Angles Machine along with 11 steel balls and drum was rotated at speed of 30-33 rpm for 500 revolutions. After that material from machine was passed through 1.7mm sieve and weight (W2) of sample passing it was noted. The abrasion value is defined to be = W2/W1 *100

Figure 3.4: Los Angles Abrasion Machine

Test	Specification		Results	Limits
Los Angles Abrasion		ASTM C 131	24.50%	**≤45%**
Specific	Fine Agg	ASTM C 128	2.617	–
Gravity	Coarse Agg	ASTM C 127	2.633	–
Impact value		BS 812	16.50%	**≤30%**
Aggregate	Fine	ASTM C 127	2.13%	**≤3%**
Absorption	Coarse	ASTM C 127	0.69%	**≤3%**
Flakiness Index		ASTM D 4791	11.20%	**≤15%**
Elongation Index		ASTM D 4791	2.94%	**≤15%**

Table 3.1: Test Results of Aggregate

Test on Bitumen:

The experimental phase of this research started with the preparation of asphalt mixes, which represent conventional Asphalt mix and modified samples in which PVC was added in different percentages. Having found the optimum asphalt content in conventional mix, optimum PVC content was determined following the presented study methodology. At the end, a comparative analysis, based on performance evaluation, of both the mixes was then carried out and important conclusions are derived. The tests made on the asphalt are as follows:

- Penetration test
- Softening Point
- Ductility Test
- Flash and Fire Point
- Specific Gravity

Penetration Test (AASHTO T 49-03):

The penetration test is used to determine the penetration grade of bitumen by measuring the depth in tenths of a millimeter up to which a standard loaded needle will vertically penetrates the bitumen specimen under given conditions of loading, time and temperature. Softer binder gives greater values of penetration. According to AASHTO T 49-03 temperature used was 25°C, load of 100 grams, while time for the test equal 5 seconds, until unless the situations are not explicitly stated. Using two ARL 60/70 specimens, five values from each specimen were taken after performing penetration tests. All values obtained fulfilled the required criteria of penetration test as per specifications. Penetration test result is presented in Table below.

Figure 3.5: Penetration Test

Softening Point (AASHTO-T-53):

The softening point is the temperature at which the substance attains a degree of softening under specified condition of test. The softening point of bitumen is usually determined by Ring and Ball test. Softening point of bitumen is the average temperature at which the two disks of bitumen soften adequate to allow the steel balls of 3.5 grams to fall 25 mm. For softening point determination of asphalt as per AASHTO T-53 specifications ring and ball apparatus was used.

Figure 3.6: Softening Point Test

Ductility (AASHTO T 51-00):

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample of the material will be elongated without breaking with a specific speed i.e. 5 cm/min and at a specific temperature of 25 ± 0.5 °C (AASHTO T 51-00).Multiple samples of bitumen were tested and all gave the ductility value greater than the least limit of 100 cm.

Figure 3.7: Ductility Test

Flash and Fire point (D3143/D3143M-13):

Flash point is that least temperature at which the bitumen momentarily flashes at specified conditions.

Fire Point is the temperature at which the material gets fire and burn under specific conditions. Flash and Fire point test was conducted as per D3143/D3143M-13 standards.

Figure 3.8: Flash and Fire Point Test

Specific Gravity (ASTM D 70):

The specific gravity is the ratio between the density of an object, and a reference substance. The specific gravity can tell us, based on its value, if the object will sink or float in our reference substance. Usually reference substance is water which always has a density of 1 gram per milliliter or 1 gram per cubic centimeter. The test was conducted as per ASTM D 70 standard.

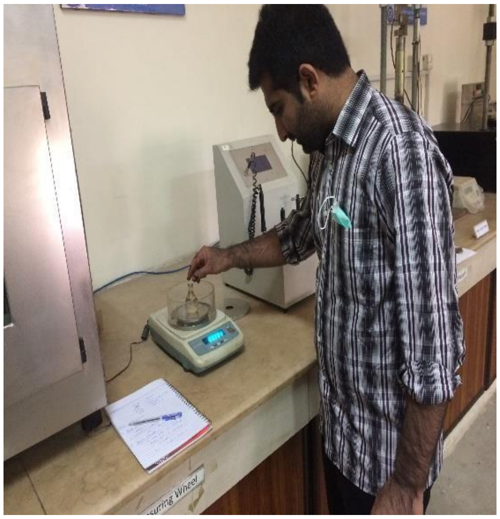


Figure 3.9: Specific Gravity Test

Results in Tabular form are:

S No.	Test Description	Specification	Results
1	Penetration Test @ 25°C	ASTM: D5-06	68
2	Flash Point (°C)	ASTM: D-92	269
3	Fire Point (°C)	ASTM: D-92	320
4	Softening Point (°C)	ASTM: D36-95	46
5	Ductility Test (cm)	ASTM: 113-99	116
6	Specific Gravity	ASTM: D 70	1.03

Table 3.2: Test Results of Bitumen

Test on Modified Binder (Bitumen + PVC):

Different tests were performed on the modified bitumen which are as follows:

Penetration Test:

Different percentages of PVC by weight of bitumen were added to the virgin bitumen and penetrations were found out. It was observed that the increasing the PVC content reduces the penetration value making the binder material harder. Results are given below:

%age of PVC in Bitumen	Penetration Value
3%	55
6%	52
9%	41

Table 3.3: Penetration Results of Modified Bitumen

Ductility Test:

Samples were tested for ductility with different PVC contents from which it was deduced that increasing the PVC content decreases the ductility values. All the values are in the range of 25-60 cm so in order to continue the research we went on to use PVC in bitumen.

%age of PVC in Bitumen	Ductility(cm)
3%	52
6%	48
9%	29

Table 3.4: Ductility Results of Modified Bitumen

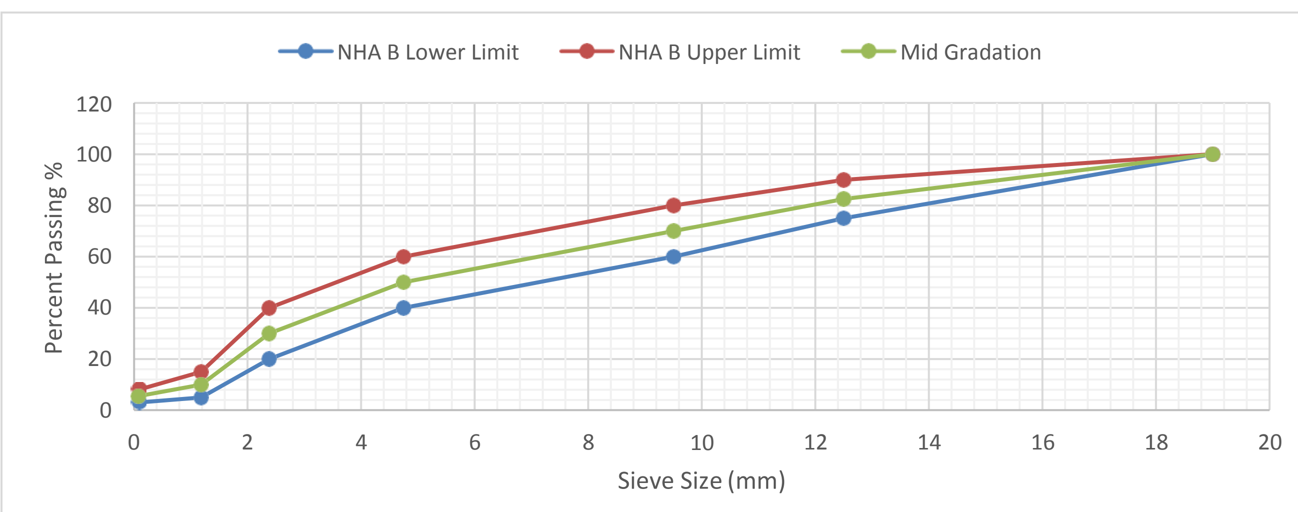
Gradation Selection:

The gradation selected was NHA gradation B for surface course mix according to NHA (1998) Specifications. The nominal Maximum size for this gradation is 19mm (3/4") according to MS2. The gradation selected is shown in table per percent passing against each sieve and corresponding gradation curve is plotted.

Table 3.5: NHA Gradation B

S.No.	Sieve Size mm	NHA Specification Range (% Passing)	Mid Gradation Selected (% Passing)	% Retained
1	19	100	100	0
2	12.5	75-90	82.5	17.5
3	9.5	60-80	70	12.5
4	4.75	40-60	50	20
5	2.38	20-40	30	20
6	1.18	5--15	10	20
7	0.075	3--8	5.5	4.5
8	Pan	-	-	5.5

Figure 3.10: Gradation Curve



Asphalt Mixture Preparation:

Two types of asphalt mixtures are prepared, one is the conventional mix having only virgin bitumen, the other having 3% PVC replacing the virgin bitumen. These specimens are prepared per Marshall Mix Design Procedure. After determination of OBC and OMC, samples were prepared for Performance Testing.

Preparation of Bituminous Mixes for Marshall Mix design:

OBC was determined through Marshall Test for virgin bitumen using different percentages of bitumen (3.5% 4% 4.5% 5% 5.5%). After sieving the Aggregate into different sizes required for the project, these aggregates were then oven dried at 110 °C. The total sample weight of Marshall Mix is 1200gm. The weight of Asphalt content varied according to its percentage which is from 3.5% to 5.5% of mix. The aggregate then used is composed of different sizes according to gradation used. Marshall Stability, flow and volumetric properties were measured to obtain OBC.

Mixing of aggregate, PVC & Bitumen:

Procedure is the same as that of preparation of virgin bitumen sample but in this case PVC is added that it replaces the bitumen by 3%.After preparation of Marshall Mix specimens were used for the performance tests.

Compaction of Specimen:

According to Marshall Mix design, there are three criteria for compaction depending on either the surface is prepared for light, medium or heavy traffic. For design purpose we consider pavement for heavy traffic so 75 blows on each side of specimen are applied to achieve compaction. The loose mix obtained from heating aggregate with bitumen is transferred to mould have base plate. A filter paper was placed below and above the specimen. After achieving 75 blows on one side, specimen was inverted and 75 blows were applied in other side of specimen. This compaction was achieved manually.

Figure 3.11: Marshall Samples

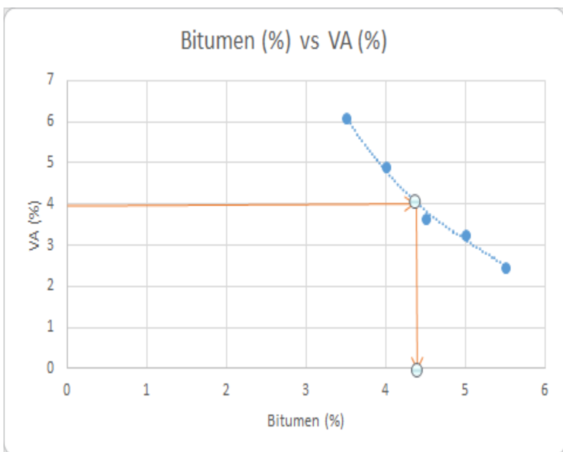
Determination of OBC:

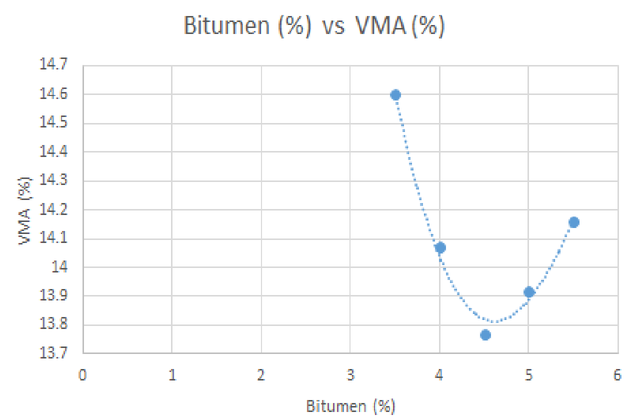
After the cooling of Specimen to room temperature the volumetric of specimen are calculated by determining Gmb and Gmm values. The tests for Gmb and Gmm are performed in accordance with ASTM D2726 AND ASTM D2041 respectively. For determination of Gmb firstly weight in air of specimen is determined, after which its weight in water and SSD weight are determined.

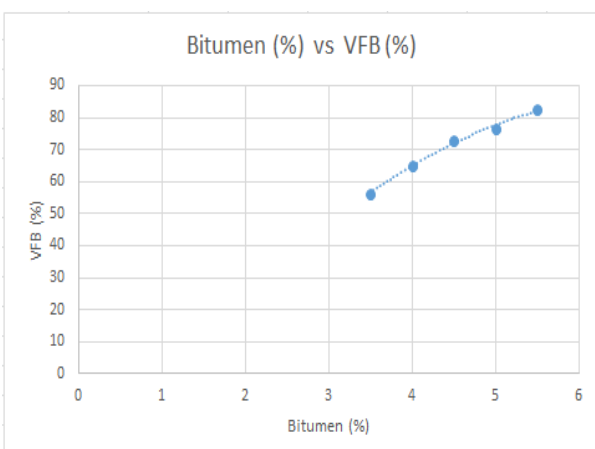
After the determination of Gmb the specimen is transferred to water bath for 30-40 minutes at 60 °C then tested for Marshall Stability and flow using Marshall Equipment. After placing the sample in Marshall Apparatus, it is loaded at constant deformation rate of 5mm/minute until the specimen fails. The maximum load that the specimen takes is its Stability value and the strain that occurs at maximum load is recorded as flow number in mm. According to Marshal Mix design Criteria MS-2, for surface designed for heavy traffic load should have Stability value not less than 8.006 KN and Flow should be between 2 to 3.5 mm.

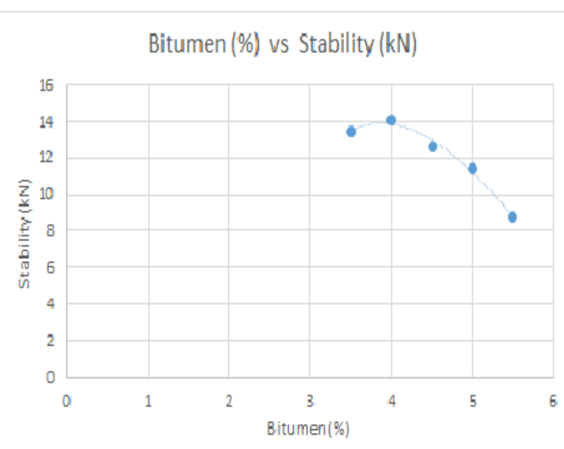
For Gmm calculation weight the loose mix, then find the calibration weight of apparatus, after that transfer the mix to apparatus and apply vacuum. After the removal of air entrapped in mix weigh again the apparatus containing mix also.

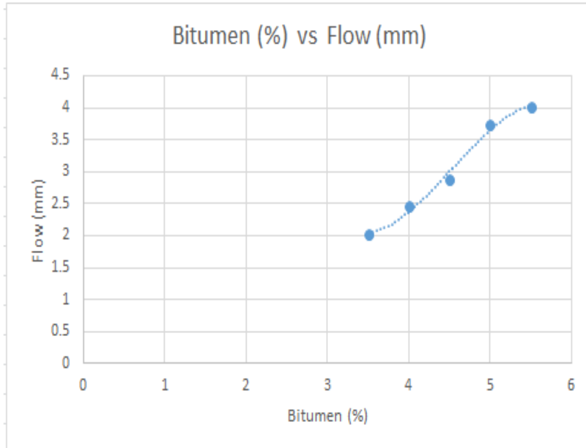
Figure 3.12: Gmm Determination











The calculated value of OBC corresponding to 4% Air Voids is 4.34%.

Preparation of Sample for Performance Tests:

After finding OBC and OMC (with respect to percent of OBC) sample for performance tests were prepared, i.e. for Moisture Susceptibility and Fatigue Tests.

Moisture Susceptibility:

The Samples for Moisture Susceptibility were prepared according to ALDOT 361, for which Marshall sample having 2.5" height and 4" diameter were prepared. The samples for moisture susceptibility falls into two categories one having virgin bitumen and the other having PVC replacing some percentage of OBC.

Fatigue Testing:

Sample for fatigue testing were prepared similarly as that for moisture testing but after the preparation of sample and conditioning of sample for 1 day the sample were cut down by saw cutting machine into required thickness, at least 1.57 inch for maximum aggregate size of 25 mm as instructed in fatigue testing standard EN 12697-24. The test should be performed after conditioning of samples for 4 hours in temperature controlled chamber at the temperature at which test is to be performed.

Moisture Susceptibility Testing:

The moisture susceptibility test were performed according to ALDOT 361-88. For each percentage of RAP and LDPE there were 2 set of samples to be tested. One sample was unconditioned sample. These samples were only placed in water bath at 25 °C for 1 hour after that test was performed. For other set namely conditioned samples, these sample were placed in water bath at 60 °C for one day followed by one hour in water bath at 25 °C. Both sets of samples were then placed in UTM machine at which load at rate of 50mm/minute is applied. The maximum load at failure was noted and tensile strength was calculated accordingly to the formula given below. The ratio of average tensile strength of conditioned sample to average tensile strength of unconditioned sample was then determined. This ratio should be minimum of 80% for satisfying the criteria of performance. The tensile strength of each subset was determined by following Equation

$$St = \frac{2000\ P}{\pi D t}$$

Where:

St = Tensile strength, kPa

P = Maximum load, N

t = Specimen height before tensile test, mm

D = Specimen diameter, mm

The TSR indicates the potential of damage caused by moisture to pavement, it is the ratio of tensile strength of conditioned sample to unconditioned sample. The TSR for each subset of specimen is determined by the following equation.

$$TSR = \left[\frac{S2}{S1}\right]$$

Where:

S1 = Average tensile strength of unconditioned Sample, and

S2 = Average tensile strength of conditioned Sample.

Fatigue Testing:

The samples prepared for fatigue testing after cutting by saw cutting machine are then placed in UTM to perform fatigue test. The method selected is indirect tensile fatigue test. The mode of loading is Stress Controlled. The specimen is subjected to Haversine load in vertical direction. This vertical compressive load produces tensile stress in the horizontal direction perpendicular to the load applied on the sample that's why it is known as indirect tensile fatigue test. The sample fails by splitting along vertical plane.

The fatigue life of a sample is defined as number of cycles to failure. In this research the load applied was 3500 N with a loading time of 0.1 seconds and a rest time of 0.4 seconds. The test was performed at 25 °C. Prior to testing the samples were conditioned for 4 hours at 25 °C. The test finishes once the sample is fractured. The number of cycles to failure is noted to draw conclusions.

Figure 3.13: ITFT Testing Using UTM

Summary:

This chapter explains the testing of Aggregate, Bitumen and Modified Bitumen. The material was then used to prepare Bituminous Mix samples. The volumetric properties of mix were calculated and OBC was determined. Then OMC was determined. The OBC alone and OBC with percent of OMC determined was then used to prepare samples for performance testing i.e. Moisture Susceptibility and Fatigue Testing. In the end of Chapter Moisture Susceptibility and Fatigue Testing methods were elaborated.

Chapter 4

RESULTS AND ANALYSIS

Introduction

This chapter will cover the results and analysis of our research, initially we used three different percentages (3%, 6% & 9%) of PVC by weight of bitumen (replacement) to determine optimum modifier content to be used further in the preparation of HMA samples for performance tests of the pavement. PVC was procured from Plasco PVC Gujrat (pvt ltd). Samples for performance tests are prepared after determining OBC. The gradation used was NHA Class B.

Results of moisture susceptibly (ITS) and fatigue test are also shown in this chapter. The details of which are given in chapter 3. Tests were performed on HMA containing PVC. Their results are finally compared with the HMA of virgin aggregate and virgin bitumen.

Optimum Modifier Content

To determine the optimum modifier content, we added three different percentages of PVC as mentioned above, then penetration and ductility tests were performed on polymer modified bitumen. The results of these tests are shown below.

%age of PVC by wt. of bitumen	Penetration Value	Ductility (cm)
3%	55	52
6%	52	48
9%	41	29

Table 4.1: PMB Test Results

After analyzing the results, we selected 3% PVC by weight of bitumen as an optimum modifier content because the penetration value of 55 is closer to 60/70 and ductility value of 52cm is greater among all three percentages. So, based on this we finalized 3% PVC as an optimum modifier content.

Moisture Induced Damage (ITS) Results

Samples were prepared for ITS and tested according to ALDOT 361-88. For HMA containing 3% of PVC as a replacement of bitumen, two samples were made for unconditioned testing and two samples were for conditioned testing. Unconditioned testing involves the requirement of keeping the specimen at 25°C for one hour and then to be tested while the conditioned samples involved the warm soaking for 24 hours at 60°C in water bath and then kept at 25°C for one hour before starting test.

Same numbers of specimens were also prepared for the HMA containing virgin aggregate and virgin bitumen. Conditioned and unconditioned tests were performed on these samples, the results of which are shown in the following table.

Sample	Mean Diameter (mm)	Mean Height (mm)	Status	Maximum Load (kN)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
V1	100	62	Unconditioned	7.285	748.03	794.14
V2	100	63	Unconditioned	8.315	840.24	
V3	100	63	Conditioned	7.215	729.08	759.16
V4	100	62	Conditioned	7.667	787.25	

Table 4.2: ITS Results for HMA containing virgin bitumen and virgin aggregate

Sample	Mean Diameter (mm)	Mean Height (mm)	Status	Maximum Load (kN)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
P1	100	62	Unconditioned	8.535	876.38	867.35
P2	100	62	Unconditioned	8.359	858.31	
P3	100	63	Conditioned	8.232	831.85	813.31
P4	100	63	Conditioned	7.865	794.76	

Table 4.3: ITS Results for HMA containing 3% PVC as a replacement of bitumen

The ITS of mix increases with the addition of PVC, since aggregate got coated with PVC and bitumen leading it to have more strength. Minimum TSR value of 0.8 is also qualified for all mixes. The TSR value decreases slightly by the addition of PVC, since the bond strength decreases when the sample is exposed to high temperature and moisture conditions. The results of TSR are obtained and shown in the following table.

Sample	TSR value (%)
Virgin	95.60
3% PVC	94.0

Table 4.4: TSR Results

-

Figure 4.1: Samples tested for Moisture Susceptibility

Fatigue (ITFT) Test Results

Fatigue test was performed by UTM according to the standard EN12697-24. This test was performed in stress controlled conditions, where stress was kept constant to increase strain in the sample. HMA samples of virgin and polymer modified bitumen (as replacement of OBC) were prepared for fatigue test. Samples with 50mm ± 1mm size with 4 hours conditioning at 25°C were tested under the loading of 3500N. The results are shown below in table

Sample		No. of Cycles	Mean Cycles
Virgin	1	3481	3629
	2	3776	
3% PVC	1	2991	3121
	2	3250	

Table 4.5: ITFT Results

As the tests are performed under stress controlled conditions. With the addition of optimum modifier content in HMA, the fatigue life of the sample was reduced slightly, since it was observed initially that the addition of PVC hardens the bitumen and ductility reduces to 52cm. This can be attributed to decreased bitumen content in sample as PVC can provide binding properties up to some extent but not like that of bitumen.

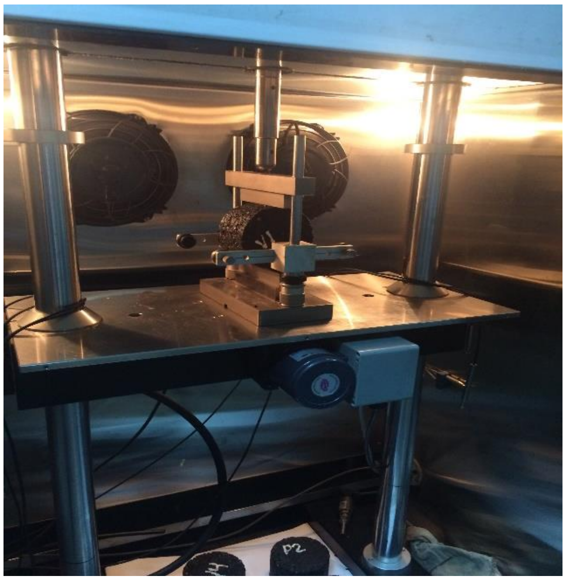


Figure 4.2: Samples Tested for ITFT

Cost Comparison of HMA with and without PVC

Among all other factors affecting cost related to road construction, material cost is the most expensive element, within which bitumen is specifically the more economically variable material so the use of waste plastics such as PVC can reduce a portion of virgin bitumen utilized in making pavement, hence reducing overall cost related to pavement construction.

In this project cost comparison was done for HMA containing 3% PVC as a replacement of bitumen. The comparison is carried out for 1km of road patch having 1 lane of 3.6m width and 2inch depth. After doing all the calculations, it was concluded that only 1.43% cost reduction is achieved which is very low since the optimum content of modifier added in HMA is also very low i.e.: 3%. Therefore, no such great reduction in cost achieved, the only good thing is the utilization of waste plastics for good purpose and making the environment more sustainable.

Summary

In this chapter, the results obtained from performance testing were analyzed and discussed briefly in detail. Comparison of results obtained from moisture susceptibility and ITFT, with and without the use of PVC is done and discussed in detail which showed that in stress controlled conditions by replacing bitumen with 3% PVC, the fatigue life of the pavement reduces. Samples containing PVC has resistance to moisture damage almost equal to that of virgin bitumen and virgin aggregate. After that cost comparison was done for control mix, mix having 3% PVC reduced the cost only by 1.43%, which is very low. It is because the optimum content of modifier added is also low. Therefore, the only good thing for using waste plastics in road construction is protecting the environment.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

Summary

This project was aimed to determine the effective use of waste PVC in asphaltic pavement, as replacement of virgin bitumen, Hot Mix Asphalt. Fatigue and Moisture induced damage are serious concerns of HMA pavement. For performance evaluation of pavement, UTM is one of the test equipment used. NHA Class B wearing course gradation, ARL Bitumen of grade 60/70 and aggregate was brought from G-11, NLC site camp which was originally from Margalla Hills, were used in this project. PVC was procured from Plasco PVC Gujrat. For determining OBC, Marshall Method was utilized. After determining OBC, two sets of samples were prepared. One set having only OBC and other having 3% PVC by replacing OBC. These samples were prepared for performance testing. The key findings of performance testing, their results and conclusions are as follows.

Conclusions

After analyzing the results of tests, following conclusions are drawn:

- Increasing the PVC content, lead to the increase in hardness of bitumen as penetration and ductility values reduced.
- 3% PVC by weight of bitumen, gives penetration value somehow closer to 60/70, i.e.: 55.
- Results show that using 3% PVC gives almost the same moisture resistance as that virgin samples. Both PVC and Virgin samples qualified the basic criteria of having minimum TSR Value of 80%.
- Results shows the no. of cycles (Fatigue Life) of the HMA containing 3% PVC, decreases in stress controlled condition.
- Addition of PVC reduces the fatigue life of the pavement.
- 3% PVC affected the overall performance of the pavement in a negative way, so it is concluded that 3% PVC is not an optimum content. Therefore, addition of PVC gives unsatisfactory results.
- Cost comparison of control mix with HMA containing 3% PVC shows that it reduces the

cost only by 1.43%.

- Since the cost reduction is very low, the good thing about using waste plastics in road construction is protecting the environment and making the environment more sustainable.

Recommendations

- In this project, indirect fatigue testing and moisture susceptibility was performed for performance testing. Other tests like rutting resistance, dynamic modulus, flow number and flow time were not performed. It is recommended to test the different blends of HMA containing optimum content of PVC for the above mentioned tests, to know about the behavior.
- Further study is recommended to check fatigue life of pavement under strain controlled conditions.
- By constructing a trial section to verify the blend for its suitability with the temperature and traffic of Pakistan.

It is recommended to use PVC in the construction of pavement for local streets, single lane roadway and for low traffic, to reduce cost.

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APPENDIX: MARSHALL MIX DESIGN REPORT

Marshall Test Report																	
Project:	FYP UG 2k14										(1) Grade AC:					ARL 60/70	
		Mass, grams of compacted Specimen						Mass, grams of loose Mix							Stability, (KN)		
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	In Air (A)	In Water (C)	Sat. Surface Dry in Air (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb =A/(B-C)	Dry Weight (a)	Calibration Weight = wt: of Pycnometer+ Glass Lid + Water (b)	wt: of Sample + Water + Pycnometer and Lid (c)	Max. S.G. (loose Mix) (Gmm) =a/b-(c-a)	Unit Wt., pcf (Mg/m3) =	% Air Voids	% VMA	% VFA	Measured	Adjusted	Flow mm
3.5-A	67.945	1195	696	1206	510	2.343	1194	6774	7490	2.498		6.196012743	13.895	55.40708801	14.83	13.199	2.183
3.5-B	66.04	1172	690	1193	503	2.330	1172	6774	7474	2.483		6.163021869	14.37664947	57.13172335	15.11	14.052	1.901
3.5-C	68.26	1182	690.3	1194	503.7	2.347	1181	6774	7483	2.502		6.214083521	13.76608225	54.85946249	14.7	13.083	1.99
Average	67.415	1183	692.1	1197.666667	505.5666667	2.340	1183	6774	7482.333	2.492		6.111953583	14.012	56.38197255	14.88	13.44466667	2.024666667
4.0-A	65.405	1188	694	1198	504	2.357	1193	6774	7485	2.475		4.7658963	13.82874551	65.53630772	15.38	14.3034	2.31
4.0-B	65.913	1142	678	1165	487	2.345	1140	6774	7453	2.473		5.17273677	14.27378404	63.76057844	14.51	13.4943	2.62
4.0-C	65	1180	693	1195	502	2.351	1178	6774	7475	2.470		4.818755538	14.06802341	65.74674781	15.12	14.5152	2.41
Average	65.43933333	1170	688.3333333	1186	497.6666667	2.351	1170.333333	6774	7471.000	2.473		4.919128132	14.05685099	65.01454465	15.00333333	14.1043	2.446666667
4.5-A	66.04	1176	694.5	1189	494.5	2.378	1178	6774	7475	2.470		3.70269913	13.51323046	72.5994525	13.57	12.6201	3.22
4.5-B	64.135	1159	681	1170	489	2.370	1153	6774	7459.5	2.466		3.899226167	13.80477123	71.75450355	13.42	12.8832	2.86
4.5-C	64.2	1169	692	1181	489	2.391	1163	6774	7467	2.474		3.389618907	13.06106779	74.04791888	12.87	12.3552	2.57
Average	64.79166667	1168.000	689.167	1180.000	490.833	2.380	1164.667	6774	7467.167	2.470		3.663563432	13.45968982	72.80062497	13.28666667	12.6195	2.883333333
5.0-A	63.5	1154	671	1154	483	2.389	1143	6774	7454	2.469		3.218257138	13.56541292	76.27601049	11.4	11.4	2.81
5.0-B	63.82	1138	665	1145	480	2.371	1139	6774	7448	2.449		3.210052678	14.23108657	77.44337608	12.97	12.4512	4.88
5.0-C	64	1156	678	1163	485	2.384	1155	6774	7460.5	2.465		3.318427277	13.77266196	75.90569429	10.5	10.5	3.5
Average	63.77333333	1149.333	671.333	1154.000	482.667	2.381	1145.667	6774	7454.167	2.461		3.248981815	13.85638715	76.55246076	11.62333333	11.4504	3.73
5.5-A	63.82	1149	676.7	1158	481.3	2.387	1148	6774	7452	2.443		2.262745135	14.09048767	83.94132844	8.82	8.4672	3.26
5.5-B	65.722	1199	707.5	1210	502.5	2.386	1198	6774	7483	2.450		2.605337254	14.13420332	81.56714464	9.5	8.835	4.373
5.5-C	65.8	1177	692	1186	494	2.383	1176	6774	7469	2.445		2.548782671	14.25938374	82.12557627	9.7	9.021	4.4
Average	65.114	1175.000	692.067	1184.667	492.600	2.385	1174.000	6774	7468.000	2.446		2.472446066	14.16135824	82.54089739	9.34	8.7744	4.011

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Sample: OBC

Identification: Margalla

Composition of Paving Mixture

		Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P					
				Bulk		Mix or Trial Number				
						1	2	3	4	5
1. Coarse Aggregate		G1		2.630	P1	54.257	53.976	53.695	53.414	53.133
2. Fine Aggregate		G2		2.618	P2	42.243	42.024	41.805	41.586	41.367
4. Total Aggregate		G4	---	2.624	Ps	96.50	96.00	95.50	95.00	94.50
5. Asphalt Cement		G5	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50
6. Bulk Sp. Gr. (Gsb), total aggregate						2.625	2.625	2.625	2.625	2.625
7. Max. Sp. Gr. (Gmm), paving mix						2.492	2.473	2.470	2.461	2.446
8. Bulk Sp. Gr. (Gmb), compacted mix						2.340	2.351	2.380	2.381	2.385
9. Effective Sp. Gr. (Gse), total aggregate						2.628	2.626	2.644	2.655	2.658
10. Absorbed Asphalt (Pba), % by wt. total agg.						0.042	0.015	0.291	0.452	0.498
CALCULATIONS										
11. Effective Asphalt content (Pbe)						3.459	3.985	4.222	4.570	5.029
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.)						13.970	14.015	13.418	13.815	14.120
13. Air Voids (Va)						6.112	4.919	3.664	3.249	2.472
14. Voids Filled with Aggregate, VFA						56.250	64.902	72.697	76.482	82.490

The End