EFFECT OF HIGH DENSITY POLYETHYLENE PLASTIC WASTE ON THE MIX DESIGN PARAMETERS OF ASPHALT

BY

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CERTIFICATION

I, KALU OJI CHUKWUDI with registration number 2017224026 hereby certify that I am responsible for the work submitted in this Thesis and that the original work which has not been submitted to this University or any other institution for the award of a degree or a diploma

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APPROVAL

This Thesis written by kalu oji chukwudi has been examined and approved for the award of Bachelor of Engineering in Civil Engineering of Nnamdi Azikiwe University, Awka.

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DEDICATION

This research work is dedicated to Almighty God for His grace, guidance, good health and wisdom given to me during the period of this research, and to my lovely parents Mr. and Mrs. Kalu Oji, and my beloved brothers and sister for their relentless support throughout the course of the programme.

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I want to express my gratitude to God Almighty for His unfathomable mercy and protection during my time at this esteemed school.

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In the name of Jesus, may the Good Lord continue to keep you all safe and prosperous. Amen.

ABSTRACT

Asphalt mix design is a critical process that involves selecting the appropriate materials and proportions to create durable and high performing hot mix asphalt. Recently, there has been growing concern about the negative impact of plastic waste, prompting researchers to investigate the feasibility of incorporating plastic waste into hot mix asphalt mixtures. This study was done to investigate the addition of High Density Polyethylene (HDPE) plastic waste to Hot Mix Asphalt for Asphalt Mix Design. The Marshall properties of the asphalt mixture for both mixtures with and without HDPE was evaluated. Results showed that the Optimum Binder Content (OBC) was 6% for the conventional mixture or the mixture without plastic. The mixture containing HDPE plastic had higher stability and flow at 4 and 10% of the plastic content respectively and the voids in the total mixture decreased with increase in the plastic waste (HDPE) content.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Eco-friendly and Sustainable projects have become the main target and concern of any agency. With the depletion of natural resources and the increase of solid wastes worldwide, different industries are looking at alternative materials (i.e., recycled materials) to be utilized in construction projects (Angelone, Cauhape Casaux and Martinez. 2016).

Recently, asphalt pavement materials costs increased tremendously, which paved the way to find alternative cheap materials. In addition, more concerns are directed to reserving natural resources and reducing environmental impacts, thus more attention is focused on the use of recycled materials in the pavement industry. (Abu Abdo. 2016).

In addition, it can be argued that carbon footprint on road construction could be reduced by using recycled materials and the use of recycled waste materials as modifier additives in hot mix asphalt (HMA) could have several economic and environmental benefits (Molenaar. 2012, Modarres and Hamedi. 2014).

Disposal of plastic waste has become a major concern worldwide due to the considerable increase in volume and growth (Angelone, Cauhape Casaux and Martinez, 2016), since it is not a biodegradable material and considered a major environmental pollutant (Siddiqui, 2009). Therefore, it would be beneficial if plastic waste could be reused in pavement construction. Recent studies were conducted to evaluate utilization of plastic waste in asphalt mixes and its effects on the performance on flexible pavements (Chavan, 2013).

Results of these studies showed asphalt mixes containing plastic waste exhibited improvement in engineering properties (i.e., Marshall stability, resistant to water, and resistant to crack propagation). Several studies investigated using plastic waste as an asphalt binder modifier to enhance its performance. Hinislioglua and Agar (2014) evaluated the use of plastic waste as an asphalt binder modifier with 4, 6 and 8% by weight of optimum binder content. Lab test results showed that mixes with 4% plastic waste yielded the highest Marshall stability and the smallest flow, and mix was also highly resistant to permanent deformation (rutting).

Al-Humeidawi (2014) evaluated the use of plastic waste to enhance the engineering properties of asphalt mixes. Results showed that Plastic Waste Modified Bitumen (WPMB) mix yielded higher Marshall Stability, higher retained stability, and higher indirect tensile strength than a conventional mix with an increase of 10% in Marshall Stability, 7% in Marshall retained stability and 9% in indirect tensile strength.

Attaelmanan et al. (2011) studied the viability of modifying asphalt binder by adding different ratios of plastic waste. Results illustrated that the penetration values and the temperature susceptibility decreased and the softening point increased with the increase of plastic waste content. In addition, modified asphalt mixes performed better than conventional mixes when it came to stability, tensile strength ratios (TSRs), and resilient modulus values at high temperatures with smaller strain values.

Modarres and Hamedi (2014) investigated the effects of adding plastic to asphalt mixes by adding plastic by 2-10% of asphalt binder weight directly as the method of dry process. They conducted resilient modulus and fatigue tests on these mixes and found that stiffness of asphalt mixes increased when adding lower amount of plastic and fatigue resistance improved for these mixes.

In order to effectively explore the use of waste plastic in pavement construction, this study will therefore evaluate the use of waste plastic as an additive in asphalt mix.

1.2. Statement of the Problem

Plastics are made up of synthetic organic polymers which are widely used in different applications ranging from water bottles, clothing, food packaging, medical supplies, electronic goods, construction materials, etc. In the last six decades, plastics became an indispensable and versatile product with a wide range of properties, chemical composition and applications. Although, plastic was initially assumed to be harmless and inert, however, many years of plastic disposal into the environment has led to diverse associated problems. Environmental pollution by plastic wastes is now recognized widely to be a major environmental burden, especially in the aquatic environment where there is prolong biophysical breakdown of plastics, detrimental negative effects on wildlife, and limited plastic removal options.

In many instances, sheeting and packaging plastics are disposed of after usage, however, because of their durability, such plastics are located everywhere and persistent in the environment. Research on the monitoring and impacts of plastic wastes is still at the infancy stage, but thus far, the reports are worrisome. In human occupational and residential environment, plastics made of petrol-based polymer are present in high quantity. At the end-of-life of these plastics, they are usually land-filled together with municipal solid waste. Plastics have several toxic constituents among which are phthalates, poly-fluorinated chemicals, bisphenol A (BPA), brominated flame retardants and antimony trioxide which can leach out to have adverse effects on environmental and public health. Plastics in electronic waste (e-waste) have become a serious global environmental and public health concern due to its large production volume and the presence of inadequate management policies in several countries. Reports from China, Nigeria, and India indicated that plastic hazardous substances from e-wastes can migrate beyond the processing sites and into the environment.

However, In an attempt to improve the durability and reliability of asphalt pavements to meet the climatic, traffic, and other requirements, the use of modified asphalt instead of raw asphalt has long been recommended as an effective approach. It has been known for some time that virgin polymers can improve asphalt performance, especially of the high-temperature stability. But virgin polymer materials are difficult to find and are uneconomical when used as modifiers. High construction costs, when combined with awareness regarding environmental stewardship, have encouraged the use of waste plastics in asphalt modification.

1.3 Aims and Objectives of Study

Research Aim

The aim of research is to study the effect of high density polyethylene (HDPE) plastic wastes on the the mix design of asphalt.

Research Objectives

The aim will be realized through the following objectives

1. To evaluate the engineering properties of aggregate used for the Asphalt mix design.
2. To determine the physical properties of bitumen.
3. To Conduct asphalt mix design of conventional Hot Mix Asphalt (HMA) in accordance with the Federal Ministry of Works and Housing Nigeria.

4. To determine the values of the mix design parameters with inclusion of different amounts of HDPE plastic wastes.

1.4 Significance of the Study

Asphalt is a thermoplastic material that demonstrates viscoelastic properties under most pavement operative conditions, thus playing an important role in pavement performance.

In an attempt to improve the durability and reliability of asphalt pavements to meet the climatic, traffic, and other requirements, the use of modified asphalt instead of raw asphalt has long been recommended as an effective approach. It has been known for some time that virgin polymers can improve asphalt performance, especially of the high-temperature stability. But virgin polymer materials are difficult to find and are uneconomical when used as modifiers. High construction costs, when combined with awareness regarding environmental stewardship, have encouraged the use of waste plastics in asphalt modification.

Various studies and research projects have been conducted to find appropriate applications of using waste plastics in asphalt production, discussing the properties of waste plastic-modified asphalt, modified mechanisms, and environmental concerns. In general, there is a desire to improve the utilization of waste plastic materials in asphalt, as long as performance is not adversely impacted. According to evidence from previous literature, utilizing waste plastic as a modifier in asphalt production provides asphalt with a similar property to virgin polymers, substantially reducing the construction cost, and protecting the environment from additional contamination.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The design of hot-mix asphalt paving involves the selection and. proportioning of two materials: mineral aggregates and asphalt cement. The selection and proportioning of these materials must meet several design objectives. The objectives of asphalt paving mix design are discussed in detail in publications such as the Asphalt Institute Mix Design Manual (Asphalt Institute, 1959). In broad terms, asphalt paving mixes must be designed to be adequate structurally for the loads imposed on them and they must be durable. Moreover, design must accomplish structural adequacy and durability economically. Mineral aggregates will normally comprise about 85% or more of the volume of an asphalt pavement. Aggregates may vary considerably in their physical properties. Because they make up the largest p art of the pavement it is reasonable that considerable importance be attached to them in paving mix design.

Asphalt cement, a thermoplastic material, makes up about 10 to 12 percent of the volume of a normal asphalt pavement. The asphalt completely coats and cements together all aggregate particles. It serves to make the pavement waterproof, abrasion resistant and durable. The combination of asphalt and aggregates in a pavement produces a resilient structure. The asphalt pavement is probably best described by the term visco-elastic. The remaining 3 to 5 percent of the volume of a pavement is air. Though not contributing directly to the structural strength some air voids are necessary in most asphalt pavements, primarily in order that adequate stability be maintained.

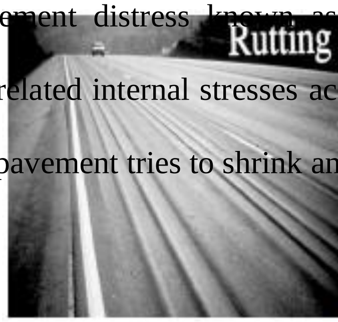
Many paving technologists long have felt that the mechanical behavior or strength properties of asphalt paving mixtures can, and eventually will, be measured by tri axial test methods (American Society for Testing Materials, 1951). Considerable research has been done and is continuing toward this end. Utilization of tri axial test methods and data however has not gained widespread use largely because of uncertainties resulting from the application of the various theories involved.

Thus, in the development of the widespread use of asphalt concrete a number of simpler tests and methods for designing and predicting the mechanical behavior of paving mixes have been developed. These are the well-known hveem, Marshall and Hubbard-Field methods which are all strictly empirical in nature. These methods when properly used, and when limited to the correlations that exist between their test values and pavement performance, are extremely useful for designing paving mixes. Some of the methods may be used effectively for controlling the manufacture of the paving mix.

Of these test methods, the Marshall has gained the most widespread use. The balance of this discussion will be related largely to the use of the Marshall method and particularly to the effect that certain aggregate variables have on Marshall test properties.

2.2 Asphalt Cement Binder Role

Asphalt cement is one of the two principal constituents of HMA pavement. It is a dark brown to black cementitious material that is either naturally occurring or is produced by the distillation of crude oil (Roberts et al., 1996). In the context of asphalt pavements, three asphalt cement binder characteristics are considered very important to the performance of the pavement in service. These are: temperature susceptibility, viscoelasticity, and aging (Roberts et al., 1996, Asphalt Institute MS No. 22, 2003). The properties of the asphalt cement binder are very dependent on its temperature. At high temperatures, asphalt cement binder becomes viscous and displays plastic response when subjected to loads higher than its viscosity at a particular temperature. This behavior under high temperature can be a contributing factor to one of the most common asphalt pavement distresses which is rutting (Figure 2.1a). In extremely cold climates, asphalt binder becomes very stiff and behaves like an elastic solid. Any induced elastic deformation is completely recovered. The extreme stiffening of the asphalt cements under such cold temperatures is the main factor for a pavement distress known as low temperature cracking. In this case, non-load environmentally related internal stresses accumulate in the pavement due to the brittle nature of the binder as the pavement tries to shrink and is restrained (Figure 2.1b)



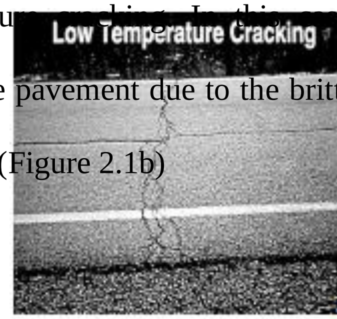


Figure 2.1 Distresses in Flexible Pavements a) Rutting b) Low Temperature Cracking (Khalid Salim Alshamsi,2006)

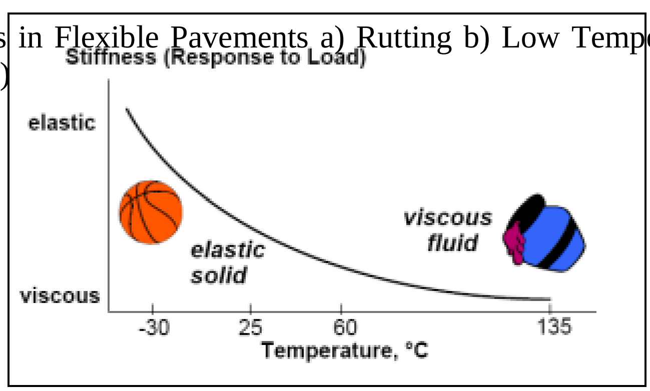


Figure 2.2 Temperature Susceptibility of Asphalt Cement Binder (Asphalt Institute SP-2, 2001)

At normal intermediate pavement service temperature, the second important asphalt binder characteristic, viscoelasticity, becomes dominant. At these temperatures, the asphalt binder has characteristics of both viscous fluid and elastic solid (Asphalt Institute SP-2, 2001). Figure 2.2 shows typical response of asphalt cement binder to change in temperature.

Asphalt cement binder behavior is also dependent on time of loading. The same load applied for different durations will result in different behaviors for the same asphalt. The dependency of the asphalt binder on both the temperature and time of loading make it possible to use these factors interchangeably. In other words, a slow loading rate can be simulated by high temperatures and a fast loading rate can be simulated by low temperatures (Roberts et al., 1996).

Chemically, asphalt binder is composed of organic molecules (hydrocarbon) and therefore reacts with oxygen. The result of this reaction is called aging. Aging is the hardening of the asphalt cement as it reacts with oxygen to the extent that it becomes brittle (Alvarez et al., 1994). Pavements with aged asphalt are more susceptible to cracking that will ultimately lead to structural and or functional failure of the pavement.

2.3 Aggregates Role

Aggregates are the second principal material in HMA. They play an important role in the performance of asphalt mixtures. For HMA, they make up about 90 to 95 percent by weight and comprise 75 to 85 percent of the volume (Roberts et al., 1996 Asphalt Institute MS No. 22, 2003). Therefore, knowledge of aggregate properties is crucial to designing high quality HMA mixtures.

Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation. Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often the byproduct of other manufacturing industries such as construction and steel industries.

An aggregate's mineral composition largely determines its physical characteristics and how it behaves in an HMA pavement. Therefore, when selecting an aggregate source, knowledge of the quarry rock's mineral properties can provide valuable information about the suitability of the resulting aggregate for HMA pavements. Regardless of the source, aggregate are expected to provide a strong, stone skeleton to resist the repeated traffic load applications. When a mass of aggregate is subjected to excessively high loads, a shear plane develops resulting in the aggregate particles sliding or shearing with respect of each others. This behavior produces what is called permanent deformation in asphalt pavement (Asphalt Institute SP-2, 2001). Along this shear plane, the applied shear stress exceeds the shear strength of the asphalt mixture (Figure2.3).

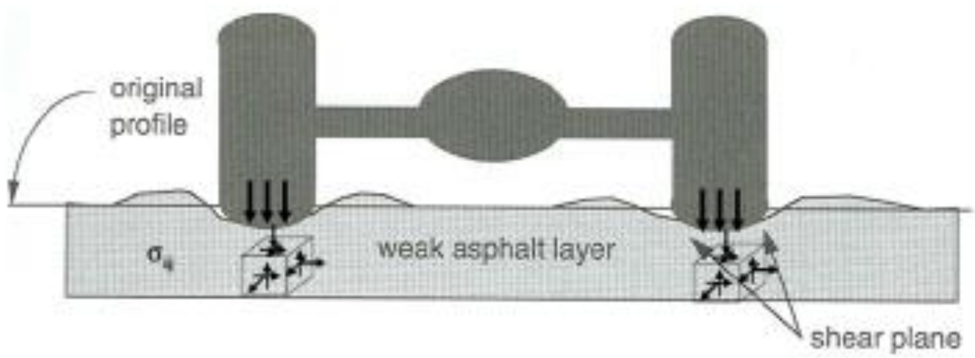


Figure 2.3 Permanent Deformation in Asphalt Mixtures (Khalid Salim Alshamsi,2006)

It is known that aggregate has relatively little cohesion (McGennis et al., 1995). The shear strength is mainly dependent on the internal friction provided by the aggregate. Here, the shape and texture of the aggregate play important role in providing the required interlock. Cubical, rough- textured aggregate provide more shear resistance than rounded, smooth-textured aggregate. The internal friction provides the ability of aggregate to interlock and create a strong mass that is able to resist the applied traffic load.

2.3.1 Aggregate Gradation

The largest portion of the mixture's resistance to the applied traffic loads is provided by the aggregate structure. Aggregate is expected to provide a strong stone skeleton to resist repeated load applications. One of the key aggregate properties that is related to asphalt mixture performance is gradation. Aggregate gradation is the distribution of the different particle sizes in a mass of aggregate expressed as a percent of the total weight (National Stone Association, 1996).

Sieve analysis is the process by which aggregate gradation is determined in the laboratory. Aggregate particles are passed through a series of sieves stacked with progressively smaller openings from top to bottom, and weighing the material retained on each sieve. Gradation of an aggregate is traditionally represented in graphical format by a gradation curve for which the ordinate is the total percent by weight passing a given sieve on an arithmetic scale, while the abscissa is the particle size plotted to a logarithmic scale as shown in Figure 2.4 (Roberts et al., 1996). For asphalt mixtures, it is generally accepted that a well-balanced, continuous gradation will provide the greatest permanent deformation resistance for any given type and quality of aggregates (Roberts et al., 1996, Ruth et al. 2002, National Stone Association, 1996).

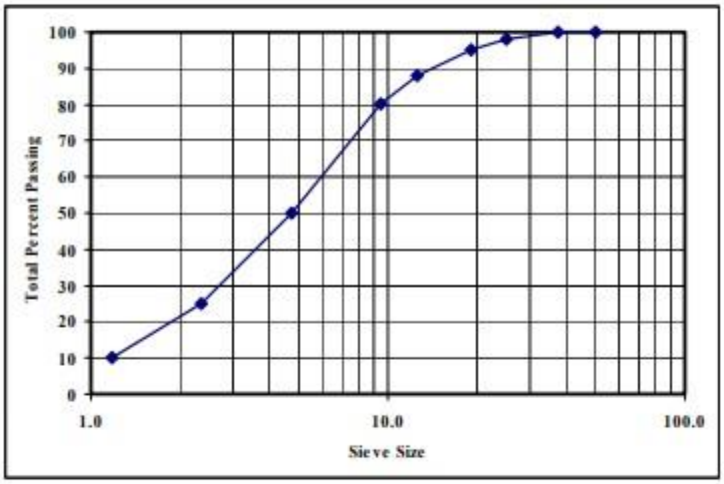


Figure 2.4 Typical Conventional Aggregate Gradation Curve (Khalid Salim Alshamsi,2006)

Gradation is considered a key factor in the resistance of mixture to permanent deformation (Ervin JR, 1989, Hveem, 1946). The most important concept is that a well balanced, continuous, gradation will provide the greatest structural strength (resistance to rutting) for any given type and quality of aggregate.

2.4 Behavior of Asphalt Mixture

The asphalt mixture resulting from blending the previous two materials, asphalt cement and aggregate will display a behavior that has combined characteristics of both materials. Therefore, the response of the HMA to the applied load depends on the thermoplastic properties of the binder and the toughness and interlock characteristics of the aggregate. When load is applied to a pavement, the primary stresses that are transmitted to the asphalt mixture are vertical compressive stress within the asphalt layer, and horizontal tensile stress at the bottom of the asphalt layer (Asphalt Institute SP2, 2001) as shown in Figure 2.5. The HMA must be internally strong and resistant to the compressive and shear stresses to prevent permanent deformation within the mixture. In the same manner, the mixture must also have enough tensile stress at the base of the asphalt layer to resist fatigue cracking after many load applications.

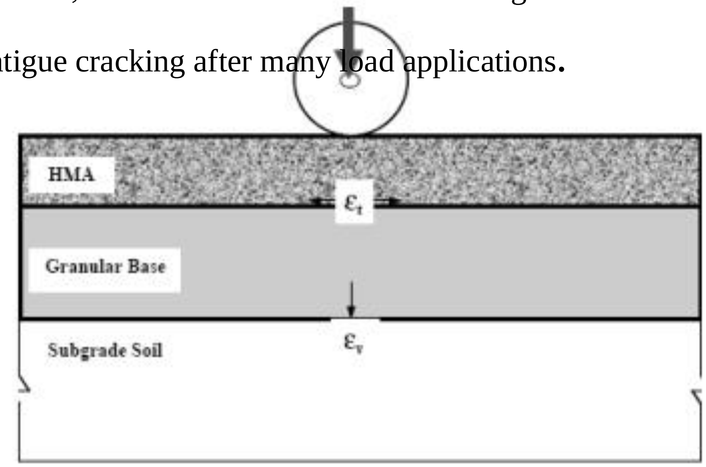


Figure 2.5 Illustrations of stresses and strains within pavement layers (White et al., 2002)

The asphalt mixture must also resist thermal stresses caused by rabid fluctuation of temperature and extremely cold temperatures. The behavior of asphalt mixture as a structural component of the pavement is normally achieved by analyzing the mixture performance under laboratory controlled conditions of load and temperature.

2.5 Mixture Design Concept

The term asphalt mixture design is being often considered as synonymous with the selection of a specific binder content normally referred to as the optimum asphalt cement content. In reality however, this is only the last step once other important factors are considered. As mentioned earlier, HMA consists of two basic ingredients: aggregate and asphalt cement binder. HMA mix design is the process of determining what aggregate to use, what asphalt cement binder to use and what the optimum combination of these two ingredients should be. HMA mix design has evolved over the years as a laboratory procedure that uses several critical tests to make key characterizations of several trials HMA blends. Although these characterizations are not comprehensive, they are intended to give the mix designer a good understanding of how a particular mix will perform in the field during construction and under subsequent traffic loading. Mixture design is a laboratory simulation of the actual HMA manufacturing, construction and performance to the extent possible. From this simulation, prediction (with some certainty) can be made of what type of mix design is best for the particular application in question and how it will perform. Mixture design is also volumetric in nature. Volume measurements however, are made indirectly by determining a material's weight and specific gravity and then calculating its volume.

2.5.1 Desirable Properties For Asphalt Concrete Mixtures

The design of asphalt paving mixture, as with the design of other engineering materials is largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structure. The common requirements for any asphalt mixtures can be summarized as follow (Asphalt Institute MS-2, 1993):

1. Resistance to permanent deformation: The mix should not distort or be displaced when subjected to traffic loads. This property is more important at high temperatures.
2. Fatigue resistance: the mix should not crack when subjected to repeated loads over a period of time.
3. Resistance to low temperature cracking. This mix property is important in cold regions Durability: the mix should contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles. The compacted mix should not have very high air voids, which accelerates the aging process.
4. Resistance to moisture-induced damage.

5. Skid resistance: This is a functional requirement that is related to safe operation of vehicles on the HMA pavement.
6. Workability: the mix must be capable of being placed and compacted with reasonable effort
7. Low noise and good drainage properties: If the mix is to be used for the surface (wearing) layer of the pavement structure.

2.5.2 Mixture Design Method

This section provides an overview of the mixture design methods that have been or being used by the asphalt industry. Generally, most of the mix design methods rely on experience and performance of mixes of known composition. Almost all mixture design methods include specimen fabrication and compaction in the mix design process to determine the mixture composition and volumetric properties.

2.5.2.1 Hubbard-Field Method

This method might be considered as the first formal design method for asphalt mixtures. It was originally developed to design sand-asphalt mixtures and later modified for aggregates (Roberts et al., 2002). The method included the compaction of 50.8 mm in diameter by 25.4 mm high specimens at a range of asphalt contents. Each specimen is heated to 140ºF in a water bath and placed in a testing mold which is in turn placed in the 140ºF water bath and a compressive load is applied at a rate of 2.4 in/min. The specimen is forced through a restricted orifice 44.5 mm in diameter. The maximum load sustained, in pounds, is the Hubbard-Field stability. After testing all of the prepared specimens, the average stability at each asphalt content is calculated and plotted to determine the optimum asphalt content. One of the problems reported in this method was the size of the test specimens which limit the use of large size aggregates greater than 12.7 mm since that would violate the ratio of 4:1 of mold diameter to maximum aggregate size (Roberts et al, 2002). The relevance of the measured stability to actual mixture performance is also a concern.

2.5.2.2 Hveem Mixture Design Method

This is one of the oldest mix design methods that dates back to 1927 when a California engineer, Francis Hveem began an extensive work to develop a mixture design method that can be reliably used by asphalt engineers and that does not solely depends on experience to reach to the optimum asphalt content (Asphalt Institute MS-2). Hveem used the aggregate surface area concept to develop a methodology for predicting the amount of asphalt needed for what used to be called oil mix (Hveem, 1942). The basis of this method is that the proper amount of binder in a mix of different size particles depends on the surface area of the gradation and that finer mixtures require higher binder content. A design chart was developed that relates the surface area to what is called bitumen index. Multiplication of surface area by the bitumen index gives the so called the oil ratio which is simply the Kilo gram of oil (binder) per Kilo gram of aggregates. A series of standard test specimens of 64.0 mm height and 102 mm diameter compacted using a special mechanical kneading compactor, with binder contents that vary around an estimated optimum value are subjected to several tests in order to arrive at the actual optimum value. The tests Hveem used to judge the fitness of the compacted mixtures were the stabilometer, cohesiometer and the swell test. The stabilometer is a predecessor of the triaxial test that utilizes a special triaxial-type testing cell and used to determine the stability of a mixture by measuring the radial expansion due to an axially applied load. Naturally, an over-filled mixture would show relatively large deformations and thus be judged unstable. The results from this test are expressed in a relative stabilometer value, where a true liquid was considered to have zero relative stability (lateral pressure equal to vertical pressure) while a non-deforming solid was the end of the range (radial deformation of zero). To account for the influence of height versus diameter ratio's, Hveem established correction curves for specimens with non-standard heights.

The second test Hveem used, the cohesiometer test, was basically a force controlled bending test. By dropping a controlled quantity of a material with a known weight per time unit in a container, the applied load steadily increased. The force necessary to arrive at a standard displacement of the loading arm is recorded as the cohesiometer value. If the bond between the aggregate particles is weak due to a lack of binder, the material will perform badly in this experiment. Finally, the swell test was be used to determine the sensitivity of the mixture to water. It measures the permeability and increase in volume due to absorption of water (swell). Hveem advised to aim for the maximum binder content that met the stability criteria and had no less than four percent air voids, to avoid the risk of (locally) over-filled material in the actual construction. The Hveem method entails a density/voids and stability analysis. The mixture's resistance to swell in the presence of water is also determined. The Hveem method has two primary advantages. First, the kneading method of laboratory compaction is thought to better simulate the densification characteristics of HMA in a real pavement. Second, Hveem stability is a direct measurement of the internal friction component of shear strength. It measures the ability of a test specimen to resist lateral displacement from application of a vertical load. A disadvantage of the Hveem procedure is that the testing equipment is somewhat expensive and not very portable. Furthermore, some important mixture volumetric properties that are related to mix durability are not routinely determined as part of the Hveem procedure. Studies over several years established a relationship between Hveem stability and stable mix performance in the field (Roberts et al., 1996): stabilometer value 35 (stable under traffic). Hveem stability characterization of asphalt concrete has been used by the road industry and is specified in ASTM D1561 and AASHTO T246.

2.5.2.3 Marshall Mixture Design Method

The basic concepts of the Marshall mix design method were originally formulated by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the U.S. Army (Asphalt Institute MS-2, 1993). It was standardized by the American Society for Testing and Materials as ASTM D-1559 “Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus. Standard test specimens of 63.5 mm height by 100 mm diameter are used that are prepared using a standard procedure for heating, mixing, and compaction of the asphalt-aggregate blend. The key features of this method of mixture design are the compaction method, volumetric analysis and the Marshall stability and flow test of the compacted specimens. The compaction is achieved by applying an impact energy using a standard hammer to compact specimens with a number of blows that are related to the expected traffic conditions. These blows are 35, 50, and 75 for low (106 ESAL) respectively. The Marshall stability is defined as the maximum load the sample can sustain at 60o C. The Marshall flow is defined as the vertical deformation of the sample in 0.01 inch units occurring at the point of maximum load. The Marshall method seeks to select the asphalt binder content at a desired density that satisfies minimum stability and range of flow values (Asphalt Institute, 1993). Basically, the Marshall stability and flow test provides the performance measure for the Marshall mix design method. The volumetric analysis includes, calculating the volumetric parameters of the mixture specimen. Measured void expressions are: air voids (Va), sometimes called voids in the total mix (VTM), Voids in the Mineral Aggregate (VMA), and Voids filled with Asphalt (VFA). In summary, the design asphalt content is determined based up on:

1. Minimum stability values based on traffic level
2. A flow value based on traffic level
3. Air void level in the range of 3-5 %
4. A minimum VMA value
5. A range of VFA values

A key advantage of Marshall method is that it requires equipment that is relatively inexpensive and very portable. The testing time is relatively short and can be conducted rapidly with little effort compared to the equipment used in the Hveem method. The volumetric analysis in this method also addresses to some extent the durability concern by specifying a range of volumetric parameters that were developed by experience and thought to act as a safeguard against environmental effects.

A major shortcoming of the Marshall method is that the impact compaction used with the method does not simulate mixture densification as it occurs in a real pavement. Furthermore, Marshall stability does not adequately estimate the shear strength of HMA. These two situations make it difficult to assure the rutting resistance of the designed mixture.

2.6 The Use of Waste Plastics in Asphalt

2.6.1 Forms of Waste Plastics Used in Asphalt

Waste plastics can be used as asphalt modifiers in a variety of forms through further processes. In the early days, waste plastics were processed into pellet form and were intended to be incorporated directly into the asphalt production plant (Nikolaides, Manthos, 2019).

These pellets were produced from 100% waste plastics, with sizes measuring between 0.3 mm and 0.5 mm. In recent years, waste plastics have begun to be processed into shredding form. However, the waste plastics in both pellet and shredding forms can only be processed through the complicated industrial system. Researchers have recently produced waste plastics as a modifier in more accepted forms by using common methods such as scissors and crushers in the lab. For example, Modarres and Hamedi (2014) cut waste PET bottles and cans into small pieces (larger than shredding) and crushed them into flake form using a special crusher, as shown in Figure 2.6c. Kumar and Garg (2011) and Lin et al (2019). made modified asphalt with waste plastics in thin strip form (20 Ã 3 mm) and fiber form (less than 2 mm). Furthermore, waste HDPE powder and electronic-plastic (e-waste) powder (as shown in Figure 2.6d) have been used as asphalt modifiers.

Figure 2.6. Various forms of waste plastics used as modifiers: (a) pellet (Fang et al 2014); (b) shredding (Modarres, and Hamedi, 2014); (c) flake; (d) powder (Balasubramanian, B 2021).

2.6.2 Approaches to Incorporating Waste Plastics into Asphalt

There are two main approaches used to incorporate waste plastics into the asphalt: the wet process and the dry process (Li, et al 2021).

In the wet process, waste plastics are added directly into the asphalt binder at high temperatures, where mechanical mixing is required to achieve a homogeneous plastic-modified binder blend. The mixing temperature and mixing time depend on the nature of the waste plastic source and asphalt binder. In the dry process, waste plastics are added directly to the asphalt mixture, either as a partial aggregate replacement or a mixture modifier (Yue, Bird, and Heidrich, 2008).When the addition of waste plastic is carried out by a wet process, the waste plastics are added to the asphalt binder to modify their properties before coming into contact with the aggregates (Movilla-Quesada, 2019). When the plastics are added using a dry process, the waste plastics are mixed with aggregates so that they actually act as reinforcement materials (Li et al., 2021).

Both the wet and dry methods have advantages as well as drawbacks, as shown in Table 1. The wet process is a conventional way of adding waste plastics, whereby they are mixed with the asphalt in a high-shear mill. Thus, the wet process requires specialized mixing and storage facilities, and it is better for controlling the properties of the modified asphalt binder. This is likely the reason why the wet method is currently the most widely used in asphalt modification. By contrast, the dry process does not require professional equipment. It can be applied in any asphalt plant without major modifications. The results from previous research have shown that the modified asphalt binder produced by the wet process has a higher viscosity, which allows a better coating of the aggregate particles, without exudation or drainage problems (Chavez, 2019).

The modified asphalt mixture produced by the dry method has relatively poor water stability (Ranieri, 2017). In terms of cost, the AC-16 mixture production materials using the dry method costs around CNY 290,000 per kilometer, which is lower than the wet method (Wang, 2017).

Table 1. The advantages and drawbacks of different processes.

Method	Production cost	Technological problem		Performance of mixture	
		Advantage	**drawback**	**Advantage**	**Drawback**
Wet process	Expensive	Normative guidance and engineering experience	Complex production process (specialized mixing and storage facilities)	Higher viscosity	Poor storage stability
Dry process	Cheap	Lack of normative guidance	Simple production process (no need of professional facility)		Poor water stability

The performances of asphalt mixtures containing different waste plastics are significantly different because of the wet or dry process. Overall, the asphalt mixtures containing waste HDPE and EVA show similar properties for both the wet and dry processes. However, the waste HDPE mixture produced using the dry process exhibits poor water sensitivity. Most previous studies focused on the wet process. The wet process is currently the most widely used for polymer asphalt modification because of its enhanced thermal behavior. However, the dry process is more cost-effective and has a simpler production process, meaning it is more convenient for waste plastic-modified asphalt production. Thus, further research is needed due to the lack of normative guidance and engineering experience for the dry process.

2.6.3 Single and Composite Modification

2.6.3.1 Single Modification

Each type of waste plastic has its own chemical composition, unique structure, molecular weight, etc., all of which affect the performance of modified asphalt when such plastics are used as a modifier independently in asphalt production.

(1) Waste LDPE

LDPE has a lower specific gravity, strength, and temperature resistance than HDPE because of its long, flexible, and linear polyethylene chain. Due to the irregular structure of the multimolecular chain arrangement of LDPE, the branched chains in asphalt combine with each other to form reticular three-dimensional structures, which can better improve the properties of modified asphalt. Thus, LDPE is widely used as a modified material for asphalt. Since the 1990s, several studies in China, Europe, the US, and the UK have reported the use of modifiers made by recycled LDPE independently. Khan et al (2016). studied waste LDPE, HDPE, and crumb rubber (CR) as an addition to base bitumen, and showed that modified asphalt binder with 10% LDPE offers the best resistance against rutting compared to HDPE and CR. Ho et al (2006). investigated combinations of three types of recycled LDPE as asphalt modifiers. The results have shown that the molecular weight and molecular weight distribution of waste LDPE have significant effects on the asphalt has low temperature performance, thermal storage stability, and polymer phase distribution. The recycled LDPE with lower molecular weight and wider molecular weight distribution is more suitable for asphalt modification, compared with high molecular weight LDPE with very narrow molecular weight distribution.

(2) Waste HDPE

As discussed above, the high crystallinity of HDPE makes it difficult to immerse in asphalt, which also affects the compatibility of modified asphalt. It is agreed that the waste HDPE-modified asphalt has higher stiffness and viscosity, and better moisture resistance (Punith et al 2011).

Costa et al (2019). indicated that waste HDPE-modified asphalt has higher stiffness and lower penetration, but worse resilience and creep recovery, compared with SBS-modified asphalt.

(3) Waste PP

Recycled PP-modified asphalt has the common characteristics of thermoplastic polyester modified asphalt, especially the superiority of high-temperature performance. However, the addition of waste PP reduces the ductility of modified asphalt and decreases the fatigue cracking performance. Specifically, the reduction of the ductility is around 20% when 5% of waste PP is added to the asphalt (Otuoze et al 2018).

Thus, it is recommended that waste PP-modified asphalt is suitable for high temperature and high-humidity areas, but the viscosity needs to be improved (Ahmedzade et al 2015).

(4) Waste PVC

Recent studies have shown that the addition of waste PVC increases the viscosity and stiffness of base asphalt so that the modified asphalt has better rutting resistance. One possible reason is that the chloride and carbon bond dipole in PVC provides a greater stiffness (Cheng, 2019).

A study by Ziari (2019) indicated that waste PVC improves the fatigue resistance, but the thermal cracking resistance is poor.

It is noteworthy that hydrogen chloride (HCL) can be formed and discharged into the atmosphere when PVC is heated to a high temperature (Costa 2013). Thus, measures should be taken to avoid air pollution.

(5) Waste PET

According to the Wellness Recovery Action Program (WRAP), PET is one of the most recycled plastic wastes (Cuadri et al 2015). Because of the high melting point, most researchers tend to use waste PET for dry modification. Results have shown that waste PET-modified mixtures developed using the dry method have an improved high-temperature performance and reduced fracture resistance when the dosage of PET is 30% and 50% (Esfandabad et al 2020).

(6) Waste PS

Waste PS-modified asphalt mixtures developed using the dry process are found to have higher rigidity, but this could be a problem in colder areas in terms of cracking resistance. Specifically, waste PS exhibits the lowest elastic behavior in the modified asphalt mixture compared with waste PE, PP, and rubber asphalt mixture using the dry process (Wu, Montalvo, 2021).

Fang et al (2014). successfully used a very low-density PS waste to expand the stiffness of asphalt and improve its rutting resistance. Hasan et al. indicated that the addition of waste high impact PS (HIPS) in asphalt improves the asphalt's stiffness, but decreases the low-temperature properties. Furthermore, much more attention should be paid to the fact that harmful substances are released when PS is heated above 70 °C.

(7) Waste EVA

Waste EVA has good compatibility with asphalt, so it has been widely studied and applied. The results have shown that the large volume of the vinyl acetate group becomes a non-crystalline area or amorphous area, which plays a role similar to rubber when EVA is mixed with asphalt. The crystalline area of EVA has high stiffness, which acts as a reinforcing bar, and greatly improves the high-temperature stability, low-temperature cracking resistance, and viscosity of modified asphalt (Gonzalez 2004).

It also exhibits certain improvements in low-temperature performance when small amounts of waste EVA are added (2â4%) (Ameri 2012).

(8) Waste ABS

The most common e-plastics used in the manufacture of electronic devices are ABS. Evidence from recent studies indicated that the use of e-plastic powders for asphalt modification helped improve the asphalt's viscosity and blending and mixing temperatures, meanwhile decreasing rutting susceptibility compared to virgin asphalt(De la Colina Martinez, 2019) .

The low temperature performance of ABS-modified asphalt is equivalent to that of virgin asphalt binders (Colbert, 2012).

Compared with waste EVA- and PE-modified asphalt, waste ABS has poor performance as an asphalt modifier, but it seems to have better storage stability. Moreover, the pavement performance of waste ABS-modified asphalt is better than unmodified asphalt. According to the Mechanistic-Empirical Pavement Design Guide (M-E PDG), using e-waste materials as modifiers for asphalt mixtures using the dry method would decrease the design thickness of the asphalt layers (Colbert, 2013).

(9) Waste PU

Bazmara et al (2018). used thermoplastic PU and synthetic PU as modifier additives in asphalt production. The results showed that the addition of synthetic PU increased the asphalt's viscosity and stiffness. Both types of PU improved the performance of base asphalt at high temperatures, including high rutting resistance and performance grade; however, they had no notable effects on asphalt performance at low temperatures. A similar result was reported by Cong, who noted that waste PU-modified asphalt had good deformation resistance, aging resistance, fatigue resistance, and high temperature storage performance. Waste PU-modified asphalt mixture developed using the wet method also had excellent water stability and deformation resistance (Sun et al., 2018).

Hot-mix asphalts with PU-modified bitumen yielded improvements in stability and lower deformation. With regard to the PU-modified mixture, Salas et al (2018). showed that, compared with the virgin sample, the PU-modified MA from the wet method exhibited lower indentation, and thus the modified mastic asphalts (MA) can be used for heavy-traffic roads.

It is evident that the addition of waste plastics can most likely increase the high-temperature stability and viscosity as well as decrease the low-temperature flexibility. Waste LDPE, PP, EVA, ABS, and PU have good compatibility with asphalt compared with other types of waste plastics, which can be seen from the summary of the rheological results of various waste plastic-modified asphalt in **Figure 2.7** The high-temperature rheological property of PP-modified asphalt was the best, followed by PE- and PVC-modified asphalt, and PS-modified asphalt was the least effective. However, further research is needed due to the difference in dosage and asphalt.

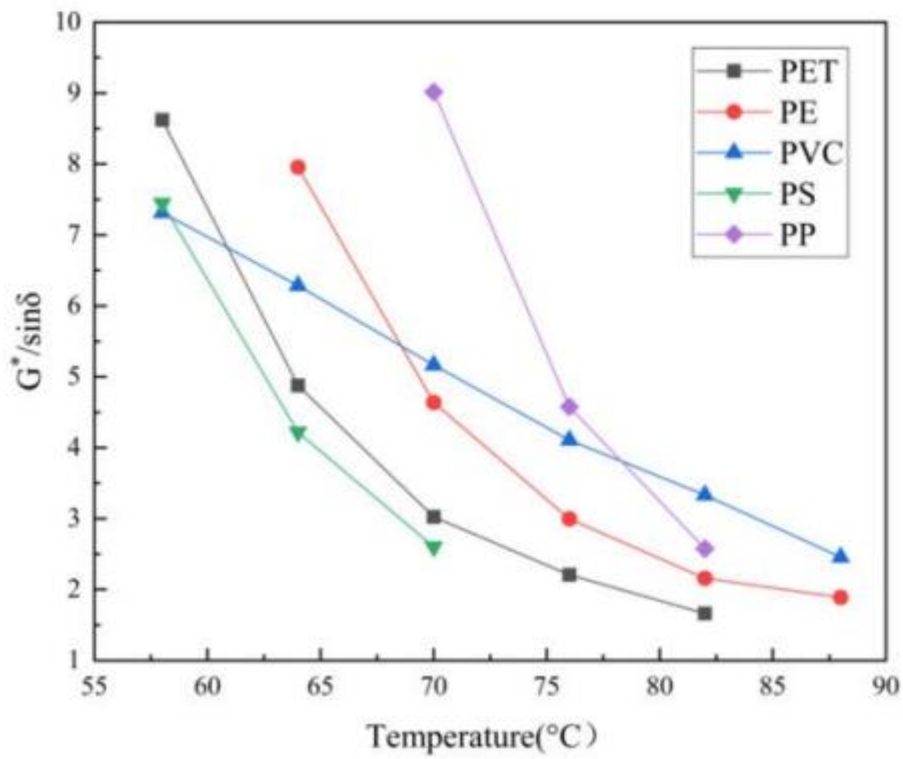


Figure 2.7 Rheological results of various waste plastic-modified asphalts (Padhan, 2018).

2.6.3.2 Composite Modification

The application of waste plastic as an independent modifier in asphalt is rare in current studies and engineering practices. This is because the key properties of asphalt cannot be improved by using only one type of waste plastic. In order to enhance and optimize the properties of waste plastic-modified asphalt binder to meet the needs of increased traffic demands, there has been growing interest in composite modification. Recently, more and more studies have investigated the properties of modified asphalt binders containing waste plastic and various materials (Vargas et al., 2021).

This interesting trend means that the application of waste plastic as an asphalt modifier has been accepted by researchers and engineering practice. Some researchers investigated modified blends containing two or more types of waste plastic. For instance, Brovelli et al (2015) and Garcia-

Morales et al (2006) assessed the high-temperature stability of base asphalt modified by combining LDPE and EVA.

Lai et al (2010). studied the compatibility and performance of waste HDPE/LDPE/PP-modified asphalt. Other researchers focused on the application of various modified blends of waste plastics and common polymers.

Nasr and Pakshir (2017) tested three melt-compounding combinations of waste PET and crumb rubber to improve the rutting and fatigue damage resistance of two base asphalt binders.

A study reported by Al-Abdul Wahhab et al (2016) suggested that waste LDPE/HDPE-modified asphalt, in combination with an elastomeric SBS, can obtain higher recovery and strain resistance, which are better than using the same amount of SBS alone.

Additionally, Krzysztof et al (2016) improved the conventional and thermal properties of asphalt by blending waste LDPE, ground tire rubber (GTR), and elastomer. Other studies have reported that waste plastics can be mixed with some common materials such as sulfur, carbon black, and polyphosphoric acid as asphalt modifiers.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This study aims to examine the effect of plastic wastes as an additive on hot mix asphalt for an asphalt mix design.

3.2 Materials Used

The major materials used for the preparation of hot mix asphalt are; aggregates, bituminous binder, fillers and plastic waste

3.2.1 Aggregates

The aggregates provided by Infrastructure Development Company (IDC) were used in the study. Aggregates constitute 94-95 percent by weight of the hot mix asphalt (HMA) mixtures. Therefore the properties of coarse and fine aggregate are very important to the performance of the pavement systems in which HMA is used. The aggregate used was granite. The following test were carried out on the asphalt sample used;

1. Aggregate gradation and sieve analysis
2. Aggregate crushing value test
3. Specific gravity

3.2.1.1 Aggregate Gradation

One of the common test performed on aggregates is a gradation (or sieve) analysis. A gradation analysis was done to determine the relative proportions of the different sizes of the aggregate particles. Aggregate gradation was done using various sieve sizes ranging from (19-0.075)mm

The different aggregate sizes used are as shown in plate 3.1;

Plate 3.1 (A) Aggregate 10-15mm, (B) Aggregate 5-10 and (c) Aggregate 0-5mm

Procedures

The aggregates were passed through a set of sieves ranging from 19mm – 0.75mm. The percentage passing of the aggregate through the selected sieve was determined by taking the weight retained on the individual sieves.

3.2.1.2 Aggregate Crushing Value Test

Aggregate crushing value test on coarse aggregates gives a relative measure of the resistance of an aggregate crushing under gradually applied compressive load.

The objective of this test is to determine the aggregate crushing value of coarse aggregate and to assess suitability of coarse aggregates for use in different types of road.

Apparatus

1. A steel cylinder 15 cm diameter with plunger and base plate.
2. A straight metal tamping rod 16mm diameter and 45 to 60cm long rounded at one end.
3. A balance of capacity 3 kg readable and accurate to one gram.
4. IS sieves of sizes 12.5mm, 10mm and 2.36mm
5. A compression testing machine.
6. Cylindrical metal measure of sufficient rigidity to retain its from under rough usage and of 11.5cm diameter and 18cm height.
7. Dial gauge

Sampling of Aggregates

Coarse aggregate passing 12.5mm IS sieve and retained on a10mm IS sieve are selected and heated at 100 to 110°C for 4 hours and cooled to room temperature. The quantity of aggregate shall be such that the depth of material in the cylinder , after tamping as described below shall be 10 cm. The appropriate quantity may be found conveniently by filling the cylinder. Measure in three layers of approximately equal depth, each layer being tamped 25 times with the tamping rod and finally leveled off using the tamping rod as straight edge. Care being taken in the case of weaker materials not to break the particles. The weight of the material comprising the test sample shall be determined (weight A) and the same weight of sample shall be taken for the repeat test.

Procedure

1. Put the cylinder in position on the base plate and weigh it (W).
2. Put the sample in 3 layers, each layer being subjected to 25 strokes using the tamping rod. Care being taken in the case of weak materials not to break the particles and weigh it (W1).
3. Level the surface of aggregate carefully and insert the plunger so that it rests horizontally on the surface. Care being taken to ensure that the plunger does not jam in the cylinder.
4. Place the cylinder with plunger on the loading platform of the compression testing machine.
5. Apply load at a uniform rate so that a total load of 40T is applied in 10 minutes.
6. Release the load and remove the material from the cylinder.
7. Sieve the material with 2.36mm IS sieve, care being taken to avoid loss of fines.
8. Weigh the fraction passing through the IS sieve (W2).

The ratio of weight of fines formed to the weight of total sample in each test shall be expressed as a percentage, the result being recorded to the first decimal place.

Aggregate crushing value = (W2 x 100) / (W1-W)

W2 =Weight of fraction passing through the appropriate sieve W1-W =Weight of surface dry sample. The mean of two result to nearest whole number is the aggregate crushing value.

The aggregate crushing value of the given sample=

Aggregate Crushing Values for Roads and Pavement Construction

The table below shows limits of aggregate crushing value for different types of road construction:

Table 2: limits of aggregate crushing value for different types of road construction.

Types of Roads / Pavements	**Aggregate Crushing Value Limit**
Flexible Pavements	
Soling	50
Water bound macadam	40
Bituminous macadam	40
Bituminous surface dressing or thin premix carpet	30
Dense mix carpet	30
Rigid Pavements	
Other than wearing course	45
Surface or Wearing course	30

3.2.1.3 Specific Gravity Test

Specific gravity test was carried out to measure the strength or quality of the material and to determine the water absorption of aggregates.

Apparatus used

1. Weighing balance
2. Specific gravity bottle
3. A thermostatically controlled oven
4. A wire basket of not more than 6.3mm mesh
5. A shallow tray and two absorbent clothes

Procedure

1. A clean dry specific gravity bottle is taken and its empty weight is determined.
2. A sample of aggregate was added to the specific gravity bottle and the weight of the bottle with aggregate was determined.
3. Water is filled up in the specific gravity bottle with aggregate sample, to just immerse sample.
4. Immediately after immersion the entrapped air is removed from the sample by shaking specific gravity bottle, placing a finger at the hole at the top of the sealed specific gravity bottle.
5. After confirming that there is no more entrapped air, it is weighed.
6. The contents of the specific gravity bottle are discharged, and it is cleaned.
7. Water is filled up to the top of the specific gravity bottle, without any entrapped air, it is then weighed.

3.2.2 Bitumen

Various test are conducted on bitumen to assess its consistency, gradation, viscosity, temperature, susceptibility, and safety.

The following test were conducted to evaluate the different properties of bituminous material.

a) Penetration test
b) Flash and fire point test

3.2.2.1 Penetration Test

The aim of this test is to determine consistency of bitumen or the grade of the bitumen by penetration test.

IS 1203-1978 Edition 2.2 (1989-03): Methods for Testing Tar and Bituminous Materials:

Determination of Penetration

Procedure

1. The bitumen is softened to a pouring consistency, stirred well and poured into the test containers.

The depth of bitumen in container is kept at least 15mm more than the expected penetration.

(I.S. 1203-1978).

2. Now the sample containers are placed in a temperature controlled water bath at a temperature of 25 c for one hour.

3. Then at the end of one hour, the sample is taken out of water bath and the needle is brought in contact with the surface of bitumen sample at that time reading of dial is set at zero or the reading of dial noted, when the needle is in contact with the surface of the sample.

4. After that the needle is released and the needle is allowed to penetrate for 5 seconds and the final reading is recorded. On that sample at least three penetration observations should be taken at distances at least 10 mm apart. After each test, the needle should be disengaged, wiped with benzene and dried. The amount of penetration is recorded.

5. The main value of three measurements is reported is the penetration test.

6. The accuracy of the test depends upon pouring temperature, size of needle, weight placed on the needle, and test temperature.

7. The grade of bitumen is specified in terms of penetration value. For example, 30/40 grade bitumen indicates the penetration value of the bitumen in the range of 30 to 40 at standard test conditions.

8. Readings are taken as units of penetration

Where, 1 unit = (1/10) mm

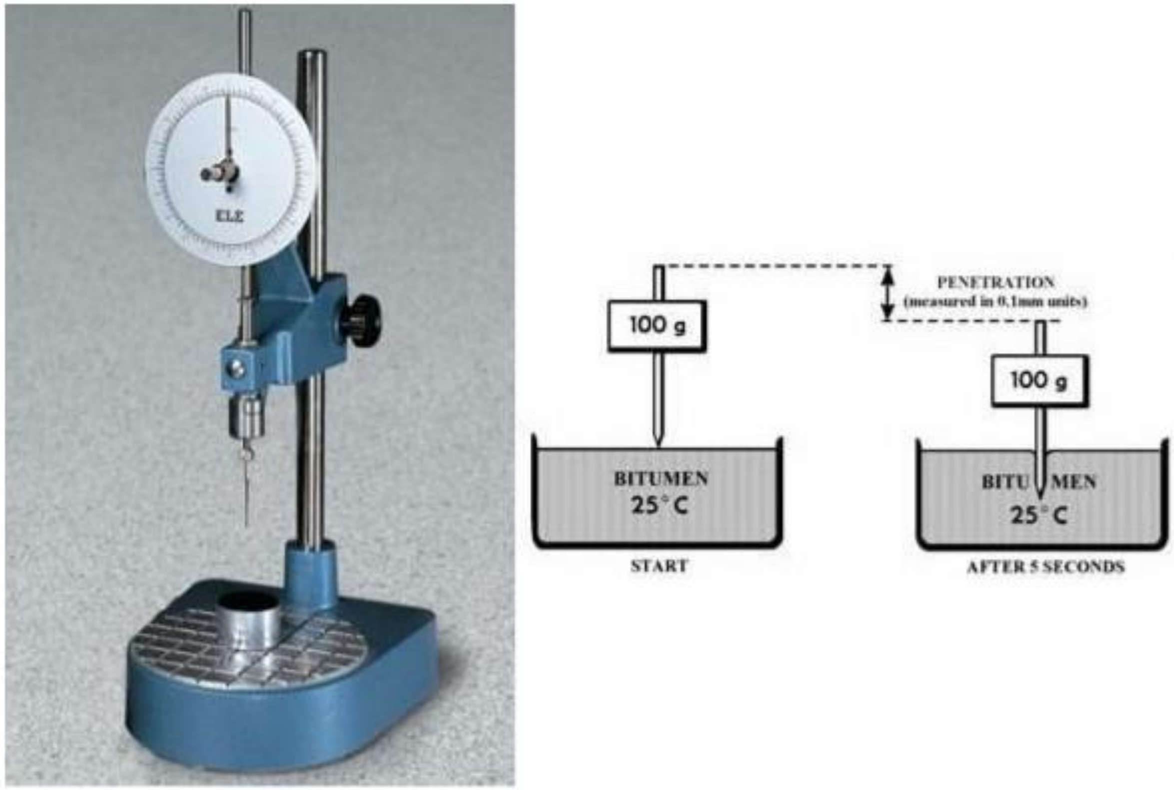


Figure 3.1:- Penetration apparatus and concept of penetration test.

Precautions during Penetration Test

a) The container should not be moved while needle penetrates into sample.

b) The sample should be free from any external materials.

c) Benzene is used to clean up the needle and dried before penetration.

d) Penetration test of bitumen is applied exclusively to bitumen. Tars being soft, penetration test on these materials cannot be carried out.

Penetration value of different types of bitumen used in road construction range between 20 to 225. However 30/40 and 80/100 grade bitumen are more common for road construction depending upon the type of construction and climate conditions. In hot 30/40 bitumen is preferred.

3.2.2.1 Flash and Fire Point Test

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And these volatiles catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade. BIS defined the flash point as the temperature at which the vapor of bitumen momentarily catches fire in the form of flash under specified test conditions.

The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

Apparatus used

a) Pensky- martens closed cup tester

b) thermometer

c) heating source

d) flame exposure

Procedure

1. All parts of the cup are cleaned and dried thoroughly before the test is started.

2. The material is filled in the cup up to a mark. The lid is placed to close the cup in a closed system. All accessories including thermometer of the specified range are suitably fixed.

3. The bitumen sample is then heated. The test flame is lit and adjusted in such a way that the size of a bed is of 4mm diameter. The heating of sample is done at a rate of 5o to 6 oC per minute.

During heating the sample the stirring is done at a rate of approximately 60 revolutions per minute.

4. The test flame is applied at intervals depending upon the expected flash and fire points and corresponding temperatures at which the material shows the sign of flash and fire are noted. At high temperatures depending upon the grades of bitumen materials leave out volatiles. And these

volatiles catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade. BIS defined the flash point as the temperature at which the vapour of bitumen momentarily catches fire in the form of flash under specified test conditions.

The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

Figure 3.2 Flash and Fire point test.

3.2.3 Plastic waste

In this investigation, HDPE (High Density Polyethylene) plastic waste was used as an additive. The HDPE plastic waste was collected from local recycling center and was melted to its liquid state. The HMA was prepared using a standard mix design with varying amounts of HDPE plastic waste. The mechanical properties of the HMA were evaluated using the Marshall Stability test, which measures the resistance of the asphalt to deformation and cracking.

Plate 3.2 plastic waste (HDPE)

3.2.4 Fillers

In bituminous mixes, filler serves two functions: it acts as an inert component and fills the spaces between bigger aggregates, giving the mixture strength and impermeability**.** The filler used in asphalt mix design was stone dust. The aggregate sample size of 0–5 mm contains stonedust. The aggregate sample was run through a 75-meter screen, and the particles that passed were employed

as fillers for stone dust. Plate 3.2 displays the aggregate size 0-5mm that was obtained from the IDC quarry in the state of Ububura.

Plate 3.3: stone dust fillers

3.3 Asphalt Mix Design Analysis

The design of asphalt paving mixes is largely a matter of selecting and proportioning materials to obtain the desired properties in the finished construction. The overall objective of the design of asphalt paving mixes is to determine an economical blend and gradation of aggregates and asphalt that yields a mix having: Sufficient asphalt to ensure a durable pavement, Sufficient mix stability to satisfy the demands of traffic without distortion or displacement, Sufficient voids in the total compacted mix to allow for a slight amount of additional compaction under traffic loading without flushing, bleeding, and loss of stability and Sufficient workability to permit efficient placement of the mix without segregation.

3.4 Marshall Method of Mix Design

In this method, the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute. There are two major features of the Marshall method of mix design. (i) density-voids analysis and (ii) stability-flow tests. The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. The flow value is the deformation that the test specimen undergoes during loading up to the maximum load. Flow is measured in 0.25 mm units. In this test, an attempt is made to obtain optimum binder content for the type of aggregate mix used and the expected traffic intensity.

Steps of Design

1. Select aggregate grading to be used

2. Determine the proportion of each aggregate size required to produce the design grading.

3. Determine the specific gravity of the aggregate combination and asphalt cement.

4. Prepare the trial specimens with varying asphalt contents.

5. Determine the specific gravity of each compacted specimen.

6. Perform stability tests on the specimens.

7. Calculate the percentage of voids, and percent voids filled with Bitumen in each specimen.

8. Select the optimum binder content from the data obtained.

9. Evaluate the design with the design requirements.

Apparatus

1. Mold Assembly: cylindrical moulds of 10 cm diameter and 7.5 cm height consisting of a base plate and collar extension

2. Sample Extractor: for extruding the compacted specimen from the mould.

3. Compaction pedestal and hammer.

4. Breaking head.

5. Loading machine

6. Flow meter, water bath, thermometers

Procedure

In the Marshall Test method of mix design three compacted samples are prepared for each binder content. At least four binder contents are to be tested to get the optimum binder content. All the compacted specimens are subject to the following tests:

a. Bulk density determination.

b. Stability and flow test.

c. Density and voids analysis.

Preparation of test specimens

The coarse aggregate, fine aggregate, and the filler material should be proportioned so as to fulfill the requirements of the relevant standards. The required quantity of the mix is taken so as to produce compacted bituminous mix specimens of thickness 63.5 mm approximately. 1200 gm of aggregates and filler are required to produce the desired thickness. The aggregates are heated to a temperature of 175° to 190°C the compaction mould assembly and rammer are cleaned and kept pre-heated to a temperature of 100°C to 145°C. The bitumen is heated to a temperature of 121°C to 138°C and the required amount of first trial of bitumen is added to the heated aggregate and thoroughly mixed. The mix is placed in a mould and compacted with number of blows specified. The sample is taken out of the mould after few minutes using sample extractor.

Plate 3.4: (A) Aggregate weighed, (B) Addition of bitumen to the aggregates

3.5 Bulk density of the compacted specimen

The bulk density of the sample is usually determined by weighting the sample in air and in water. It may be necessary to coat samples with paraffin before determining density. The specific gravity Gbcm of the specimen is given by

$$Gbcm = Wa/Wa-Ww$$

where,

Wa = weight of sample in air (g)

Ww = weight of sample in water (g)

3.6 Stability test

In conducting the stability test, the specimen is immersed in a bath of water at a temperature of 60°± 1°C for a period of 30 minutes (Plate 3.3 A). It is then placed in the Marshall Stability testing machine (Plate 3.3 B) and loaded at a constant rate of deformation of 5 mm per minute until failure. The total maximum in kN (that causes failure of the specimen) is taken as Marshall Stability. The Stability value so obtained is corrected for volume. The total amount of deformation is units of 0.25 mm that occurs at maximum load is recorded as Flow Value. The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds.

Plate 3.5: (A) Specimen placed in the water bath, (B) Specimen placed in the Marshall Stability testing machine.

Results and Calculations

Following results and analysis is performed on the data obtained from the experiments.

Bulk specific gravity of aggregate (Gbam)

Since the aggregate mixture consists of different fractions of coarse aggregate, fine aggregate, And mineral filler with different specific gravities, the bulk specific gravity of the total aggregate

In the paving mixture is given as

$$Gbam = \frac{Pca + Pfa + Pmf}{\frac{Pca}{Gbca} + \frac{Pfa}{Gbfa} + \frac{Pmf}{Gbmf}}$$

Where,

Gbam= bulk specific gravity of aggregates in paving Mixtures.

Pca, Pfa, Pmf= percent by weight of coarse aggregate, fine Aggregate, and mineral filler in paving mixture.

Gbca, Gbfa, Gbmf=bulk specific gravities of coarse aggregate, fine Aggregate, and mineral filler, respectively.

Maximum specific gravity of aggregate mixture (Gbam)

The maximum specific gravity of aggregate mixture should be obtained as per ASTM D2041,

However because of the difficulty in conducting this experiment an alternative procedure could

Be utilized to obtain the maximum specific gravity using the following equation:

$$Gbam = \frac{Pca + Pfa + Pmf}{\frac{Pca}{Gbca} + \frac{Pfa}{Gbfa} + \frac{Pmf}{Gbmf}}$$

where,

G mp= maximum specific gravity of paving mixtures.

Pca, Pfa, Pmf= percent by weight of coarse aggregate, fine aggregate, and mineral filler in paving mixture.

Gbca, Gbfa, Gbmf=bulk specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively

Percent voids in compacted mineral aggregate (VMA)

The percent voids in mineral aggregate (VMA) is the percentage of void spaces between the Granular particles in the compacted paving mixture, including the air voids and the volume Occupied by the effective asphalt content.

$$VMA = 100 - \frac{GbcmPta}{Gbam}$$

where,

VMA=percent voids in mineral aggregates.

Gbcm=bulk specific gravity of compacted specimen

Gbam=bulk specific gravity of aggregate.

Pta=aggregate percent by weight of total paving mixture.

Percent air voids in compacted mixture (Pav)

Percent air voids is the ratio (expressed as a percentage) between the volume of the air voids between the coated particles and the total volume of the mixture.

$$Pav = 100\frac{Gmp - Gbcm}{Gmp}$$

where,

Pav=percent air voids in compacted mixture

Gmp=maximum specific gravity of the compacted paving mixture

Gbcm=bulk specific gravity of the compacted mixtures

3.7 Determination of Optimum Binder Content

Five separate smooth curves are drawn with percent of asphalt on x-axis and the Following on y-axis

•unit weight

•Marshall stability

•Flow

•VMA- Voids in mineral aggregates.

• VTM - Voids in total mix (Pav)

Optimum binder content is selected as the average binder content for maximum density, Maximum stability and specified percent air voids in the total mix. Thus

$$B0 = \frac{B1 + B2 + B3}{3}$$

where,

B0=optimum Bitumen content.

B1=% asphalt content at maximum unit weight.

B2=% asphalt content at maximum stability.

B3=% asphalt content at specified percent air voids in the total mix.

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 Aggregate

According to the requirements given by the federal ministry of works and housing Nigeria, laboratory testing was done on the aggregates used for the mix design.

4.1.1 Aggregate Gradation

The range of aggregate to be used in the asphalt mix design was tested. Table 4.1 displays the aggregate sizes utilized for the mix design and their percentages; Table 4.2 displays the average of the passing percentages for each size of aggregate used as well as the lower and higher limits for each sieve size.

Table 4.1 Size of the aggregate and the proportion utilized for Gradation

Sample	Aggregate size	Percentage mix
Sample 1	10-15 mm	15.0
Sample 2	5-10 mm	12.0
Sample 3	0-5 mm	73.0

Table 4.2 Sieve analysis

Sieve sizes mm	**(10-15)mm**		**(5-10)mm**		**(0-5)mm**		**Combined mix**	**Specifications**	
	Percent passing	**15.0%**	**Percent passing**	**12.0%**	**Percent passing**	**73.0%**	**100**	**LL(%)**	**UL(%)**
19.0	100	15	100	12	100	73	100	100	100
12.0	78.8	11.8	100	12	100	73	96.8	85	100
9.5	8.9	1.3	98.6	11.8	100	73	86.1	75	92
6.3	0.5		51.5	6.18	98.9	72.2	78.4	65	82
2.36	0.3		8.5	1.02	79.2	57.8	58.8	50	65
1.18			4.2	0.5	51.9	37.9	38.4	36	51
0.600			3.4	0.4	40.5	29.6	30.0	26	40
0.300			2.6		29.1	21.2	23.8	18	30
0.150			2.0		20.0	14.6	16.6	13	24
0.075					15.6	11.4	11.4	7	14

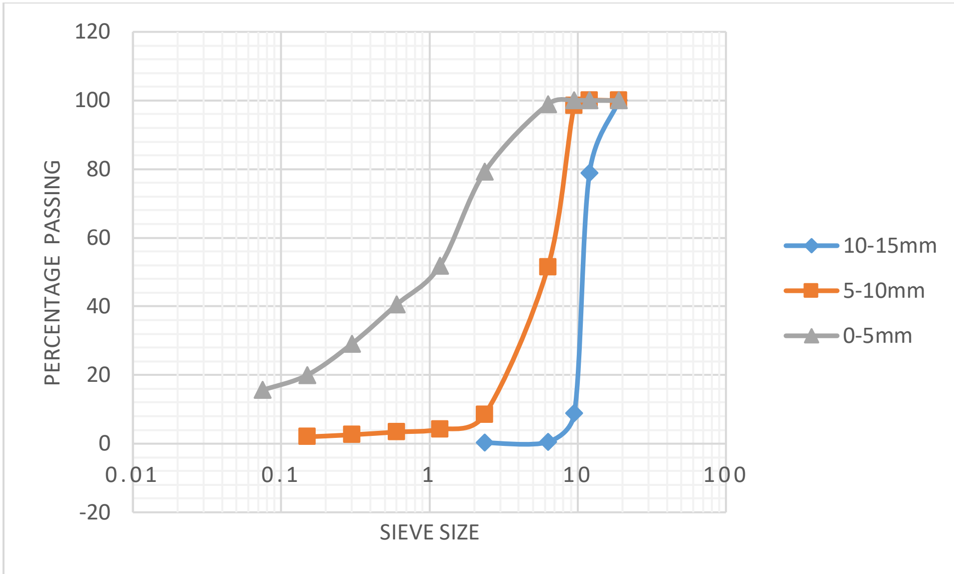


Figure 4.1: Aggregate Gradation used for asphalt mix design

Figure 4.1 show the particle size distribution curve for each aggregate sizes used for the asphalt mix design.

4.1.2 Aggregate Crushing Value

The 10-15 mm aggregate size was used for the aggregate crushing test since it is the largest aggregate size and can support most weight. Table 4.3 presents the test's findings.

Table 4.3 Aggregate Crushing Value for (10-15)mm

Sample No	**Weight in Mould(g)**	**Weight passing 2.36mm sieve**	**Aggregate crushing value**
A	3798.5	695.2	18.3
B	3962.6	710.5	17.9
C	3872.8	723.1	18.7
AVERAGE			18.3

By calculating the average of the three used samples, the test's aggregate crushing value of 18.3% was determined. According to BS812: part 3, the average crushing value limit for surface or wearing course is 30%. Since the aggregate crushing value is 18.3 and less than the established 30% limit, the aggregates obtained from the quarry are adequate for the design of an asphalt mix.

4.1.3 Specific Gravity Test

The test result for the specific gravity test for aggregate size (10–15 mm) is shown in table 4. The specific gravity test was performed in line with the guidelines established by Nigeria's federal ministry of works and housing.

Table 4.4 specific gravity test result

	TEST NO		**1**	**2**
a	Weight of Empty Bottle		497.8	497.8
b	Weight of Bottle + Water		1508.6	1508.8
c	Volume of Bottle	**(b – a)**	1010.8	1010.8
d	Weight of Bottle + sample		1092.6	1077.8
e	Weight of sample	**(d – a)**	594.8	580.0
f	Wt. of bottle+ sample + water		1894.2	1880.3
g	Water added	**(f – d)**	801.6	802.5
h	Water displaced	**(c – g)**	209.2	208.3
i	Temperature of water		25	25

	Specific Gravity	2.85	2.79

The average specific gravity of both samples was taken and used for the asphalt mix design.

4.2 Bitumen Characterization

The bitumen utilized for the asphalt mix design underwent a test, and the results are displayed in table 4.5 as a consequence. The purpose of the test was to assess whether bitumenous binder was appropriate for use in asphalt mixes. Because the penetration value obtained from the test showed that the penetration was 64mm and it comes within the limit for wearing course, the outcome indicated that the bitumen had a 60/70 grade.

Table 4.5 Bitumen Characterization Result

Test	**Result**	**Specified Limit (FMWH, 1997)**
1. Penetration (mm)	64	60-70(wearing course)
2. Specific gravity	1.03	1.01 – 1.06
3. Fire point	305	>302
4. Flash point	264	>250

The bitumen underwent a specific gravity test, and the result was 1.03, which is within the acceptable range. A flash and fire point test was also conducted to determine the safest temperature for bitumen exposure, and the results met the criteria. As a result, the bitumen is adequate and can be utilized in the design of an asphalt mix, according to the bitumen test result.

4.3 Asphalt Mix Design

The asphalt concrete mix was designed using the Marshall method. 1200g of the aggregate were used in total, before different amounts of bitumen were added as shown in Table 4.1 and 4.2.

Table 4.6 Mix percentages used for Asphalt mixtures with stone dust filler.

Sample No	Mix percentage	Weight	Cumulative weight
Sample 1: (10- 15)mm	15%	180g	180g
Sample 2 : (5-10)mm	12%	144g	324g
Sample 3: (0-5)mm	73%	876g	1200g

Weight of bitumen added for 5.0% = $\frac{5}{100} \times \frac{1200}{1} = 60g$

Weight of bitumen added for 5.5% = $\frac{5.5}{100} \times \frac{1200}{1} = 66g$

Weight of bitumen added for 6.0% = $\frac{6}{100} \times \frac{1200}{1} = 72g$

Weight of bitumen added for 6.5% = $\frac{6.5}{100} \times \frac{1200}{1} = 78g$

Weight of bitumen added for 7.0% = $\frac{7}{100} \times \frac{1200}{1} = 84g$

The link between different binder percentages and the attributes of the mixtures, such as bulk density, void in total mix (VTM), void in mineral aggregate (VMA), void filled with asphalt (VFA), Stability and flow, is illustrated as shown in Table 4.2

Table 4.7 Asphalt mixture properties at their representative binder contents

Binder%	Bulk density (g/cm^3)	VTM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
5.0	2.282	10.75	21.85	50.80	9.60	2.2
5.5	2.330	8.20	20.62	60.33	10.7	2.8
6.0	2.398	4.60	18.70	74.90	12.6	3.4
6.5	2.340	3.90	20.93	70.71	12.5	3.8
7.0	2.300	3.10	22.89	68.28	10.3	4.0

4.4 Asphalt Mix Design using Plastic Waste as an Additive

The total weight of aggregate used was 1200g and bitumen of 6% which was gotten as the optimum binder content of the asphalt was added to the mixture. The type of plastic waste used was High Density Polyethylene (HDPE) plastic which was melted to its liquid state and then added to the mix in various percentages ranging from 2, 4, 6, 8 and 10 of bitumen weight. This is shown in Table 4.3. The Marshall method of mix design was adopted for the asphalt mix design.

Weight of plastic added for 2% = $\frac{2}{100} \times \frac{60}{1} = 1.2g$

Weight of plastic added for 4% =$\frac{4}{100} \times \frac{60}{1} = 2.4g$

Weight of plastic added for 6% =$\frac{6}{100} \times \frac{60}{1} = 3.6g$

Weight of plastic added for 8% =$\frac{8}{100} \times \frac{60}{1} = 4.8g$

Weight of plastic added for 10%= $\frac{10}{100} \times \frac{60}{1} = 6.0g$

Table 4.3 displays the correlation between various plastic percentages by bitumen weight employed and mixture characteristics such as bulk density, void in total mix (VTM), void in mineral aggregate (VMA), voids filled with asphalt (VFA), Stability and flow.

Table 4.8 Asphalt mixture properties at their respective plastic percentages by bitumen weight

Binder	**Bulk density (g/cm^3)**	**VTM (%)**	**VMA (%)**	**VFA (%)**	**Stability (KN)**	**Flow (mm)**
2.0	2.248	10.73	23.80	55.04	11.08	2.4
4.0	2.282	9.37	22.67	58.62	14.24	3.1
6.0	2.387	5.20	19.11	72.74	13.86	3.2
8.0	2.312	4.40	21.66	62.19	13.11	3.4
10	2.301	3.50	24.50	52.94	10.92	3.6

A plot of bulk density with bitumen content is shown in Figure 4.2. With regard to fluctuations in binder content, it has a crest curve.

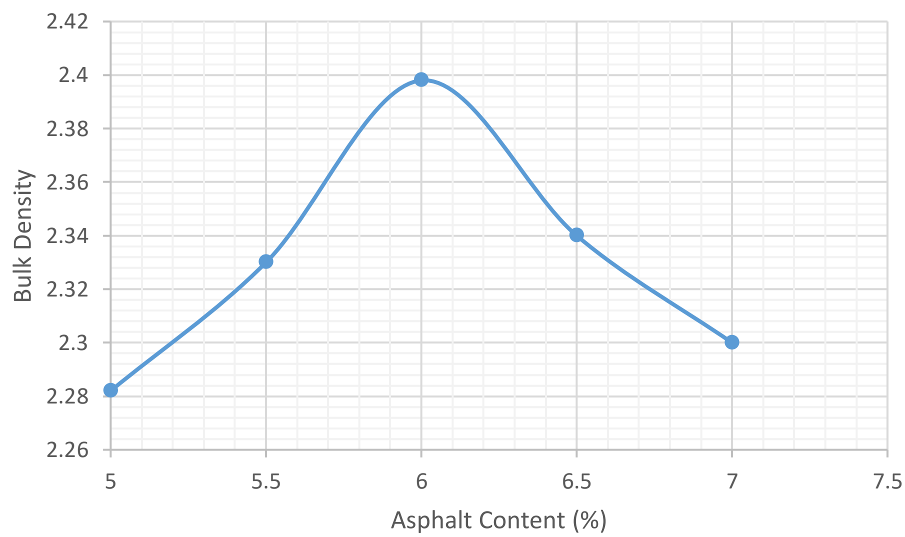


Figure 4.2 Bulk Density with Asphalt Content

The greater compaction they achieve and the less bulk volume they have, the higher the binder content is. This permits a steady increase in bulk density up to a peak value before the bulk densities start to decline. The bulk density of an asphalt mixture incorporating stone dust filler was 2.398g/cm^3 at the optimal binder level of 6.0%.

Figure 4.3 demonstrated that using less binder caused the void in the total mix (VTM) to grow. For the asphalt combination with stone dust filler, the vacancy in the overall mix was greater at a 5% binder level.

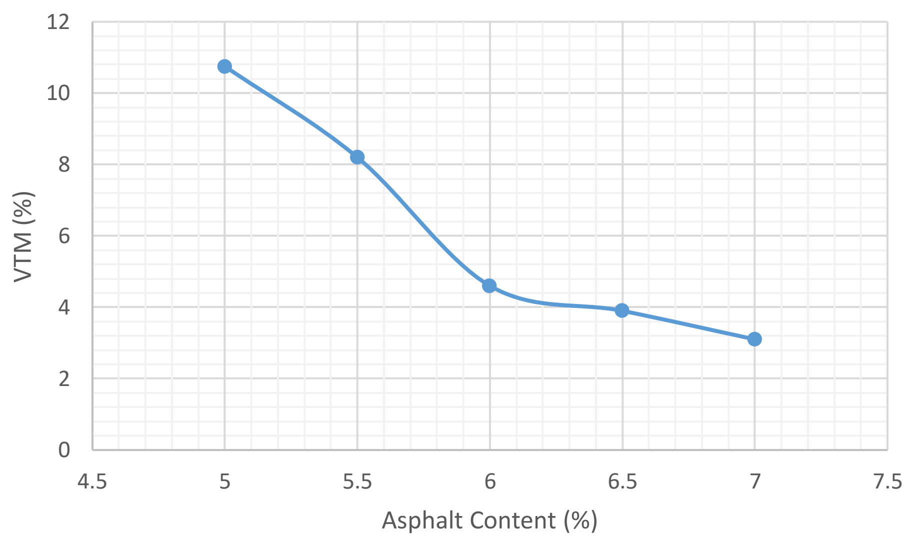


Figure 4.3 Voids in total mix (VTM) with asphalt content

The Void in Total Mix (VTM) decreases with an increase in the percentage of asphalt component in the mixture, according to an analysis of the results. According to the data's graphical representation, there is a negative correlation between VTM and asphalt content, with

VTM falling as asphalt content rises. These results are important for figuring out the ideal amount of asphalt to add to a given combination to get the degree of VTM that is needed. Appropriate VTM levels can be obtained by regulating the asphalt content, which eventually improves the stability and durability of the pavement.

Figure 4.4 depicts how the amount of binder affects the amount of voids in the mineral aggregate (VMA).

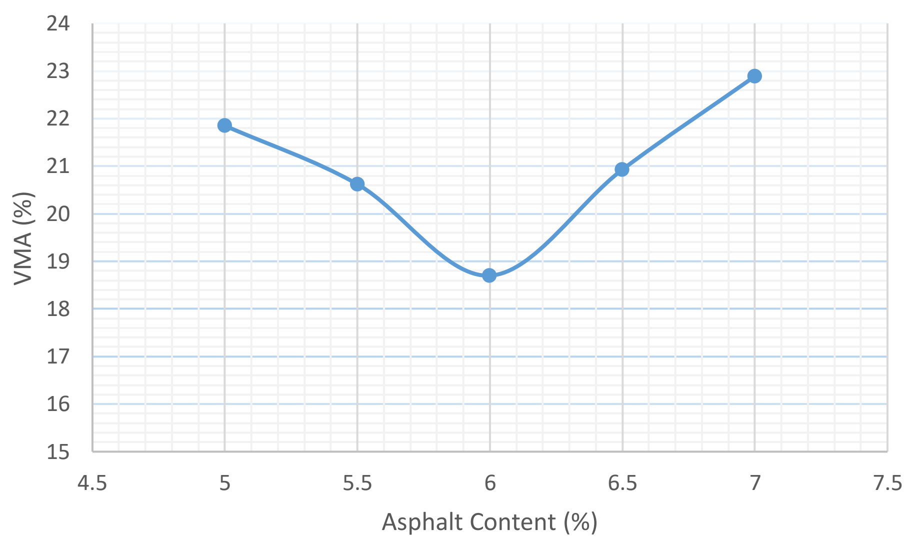


Figure 4.4 VMA with Asphalt Content

The bulk density of asphalt mixtures is mathematically inversely correlated with its VMA (Muniandy & Sohadi, 2001). Therefore, it makes sense why the bulk density curves are crest curves and the VMA curves are sag curves.

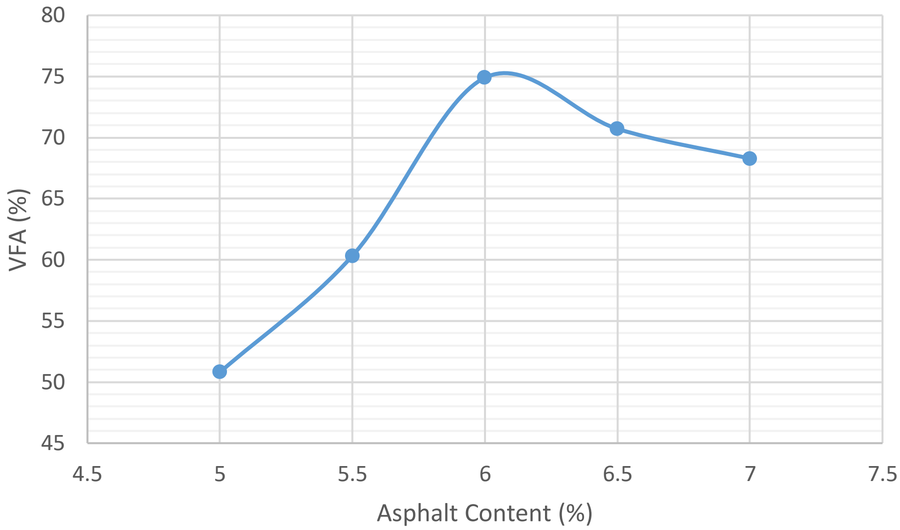


Figure 4.5 VFA with Asphalt Content

After observing and analyzing the results obtained from the experiment measuring Voids Filled with Asphalt (VFA), it can be concluded that the VFA increases as the percentage of asphalt content in the mixture increases. The graphical representation of the data clearly shows a positive correlation between the VFA and the asphalt content. This data is useful in determining the optimum asphalt content for a given mixture to achieve a desired level of VFA.

The stability values are shown in Figure 4.6 for different bitumen percentages. The Marshall stability test measures the asphalt mixture's resistance to compressive stresses. The highest compressive load that the specimen might withstand is the stability.

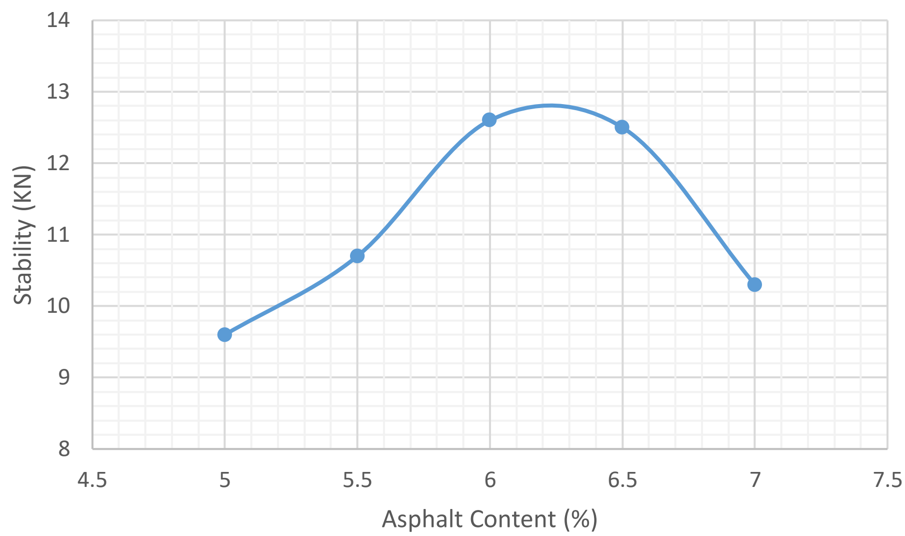
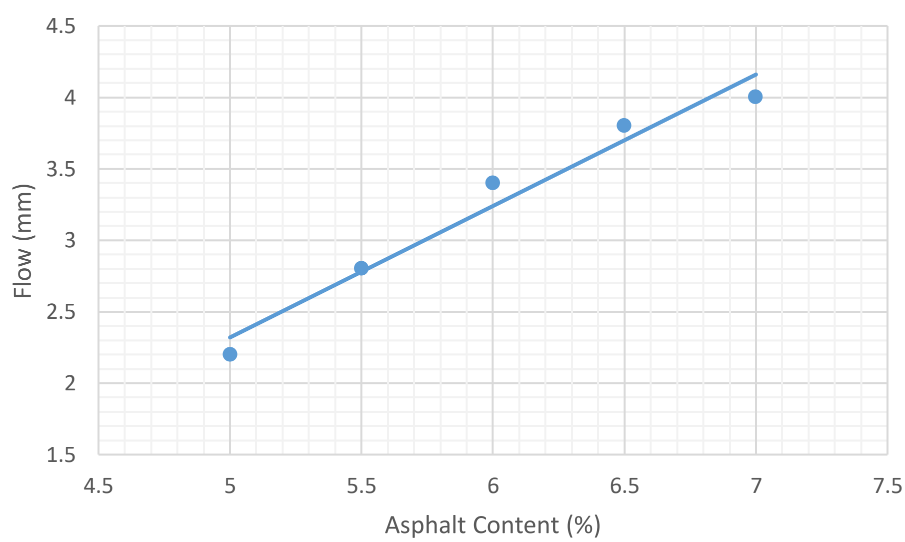


Figure 4.6 Marshall Stability with Asphalt Content

The peak stability curves are used to determine the ideal binder content (OBC). The OBC occurred in the asphalt mixture with stonedust filler at a 6% asphalt concentration.

A plot of the flow vs asphalt content is shown in Figure 4.5. The positive straight line curve illustrates how the flow increased along with the binder content.



Figures 4.7 Flow with Asphalt Content

In an asphalt combination with stonedust filler, the flow value is 2.1%, with 5% asphalt content producing the lowest flow value. At a 7% binder concentration, the flow value reached its maximum level and was 4.0%.

4.5 Addition of plastic waste at an optimum binder content of 6%

High Density Polyethylene plastic was added to the mix in various percentages ranging from 2, 4, 6, 8 and 10 of bitumen weight. The various graphs shows the relationship between the asphalt mixture properties with added plastic waste at 6% binder content

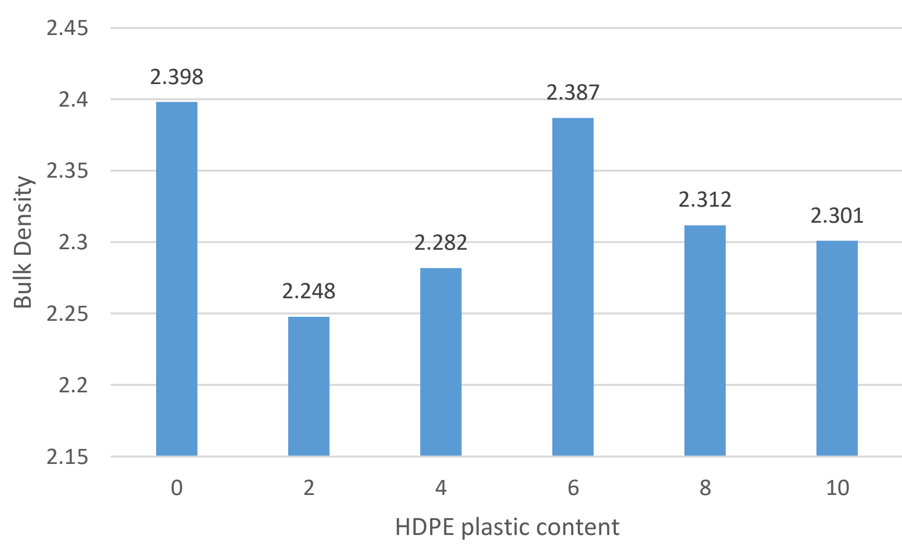


Figure 4.8 bulk density with HDPE plastic

Figure 4.8 shows the addition of various amounts of HDPE plastic to the asphalt mixture. It can be observed that at 0% of HDPE plastic the bulk density is highest. As greater compaction was achieved the higher the bulk density with addition of HDPE plastic waste.

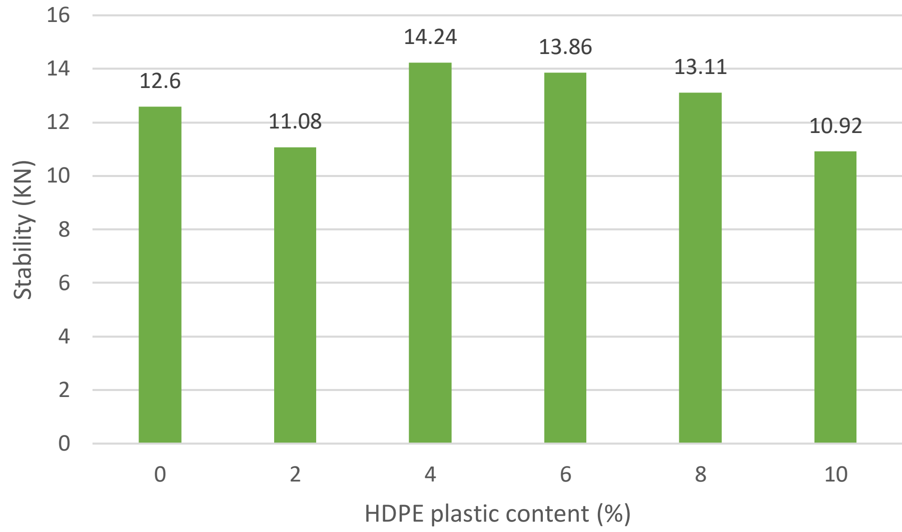


Figure 4.9 Stability with HDPE plastic.

Figure 4.9 shows the values of stability at various percentages of HDPE plastic. From the chart it can be observed that HDPE plastic had a higher stability at 4% than that of the conventional mix or asphalt mix without plastic waste.

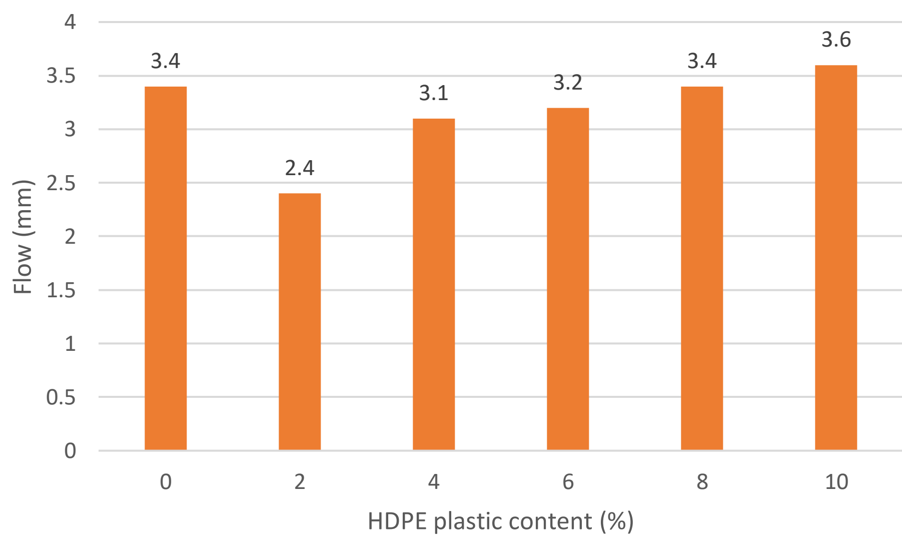


Figure 4.10 Flow with HDPE plastic.

Figure 4.10 is a plot of flow against HDPE plastic content. For the asphalt mix containing the plastic waste it can be observed that the lowest flow occurred at 2% of the plastic waste content and the maximum flow value occurred at 10% of the plastic waste content. This indicates that the internal friction of the mixture would reduce by adding plastic waste. Also the flow of the conventional mix was lower than that of the mix containing HDPE plastic.

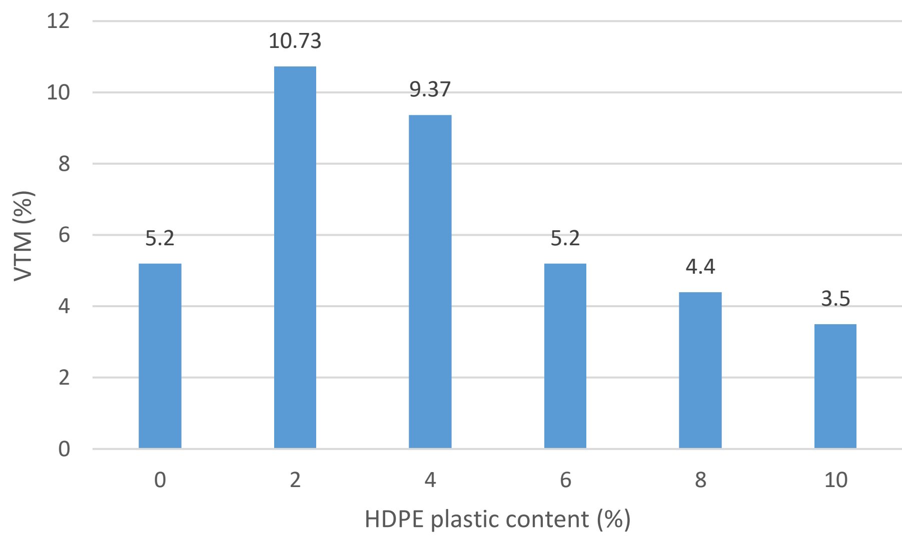


Figure 4.11 Voids in Total Mix with HDPE plastic

Figure 4.11 shows the variations between HDPE plastic and the Voids in the Total mix of the asphalt. It is observed that at 0% of the HDPE the voids in the asphalt is lower, and as the amount of plastic waste increases the voids in the total mix reduces.

4.6 Optimum Binder Content for Asphalt Mixture Containing Stone dust filler and HDPE plastic.

The maximum amount of binder obtained complies with the Federal Ministry of Works and Housing (1997) regulation, which states that the ideal amount of binder in asphalt concrete should range from 5 -8%. It was shown that the stability of the asphalt mix is directly correlated with the bulk density of the mixture. Up until the ideal binder amount (6%), bitumen percentages lowered the void in mineral aggregate, void in the whole mix, and void filled by bitumen. As the bitumen % was increased, the asphalt mixture flowed more easily. With the exception of the void in the total mix for stone dust filler which fell slightly above the standard in the specification provided by the Federal Ministry of Works and Housing in 1997, it was determined that the control mix attributes complied with it.

Table 4.9 Asphalt mixture parameter at different Optimum Binder Content

Property	**Specification (FMWH,1997)**	**Stone dust Filler**	**HDPE Plastic**
Optimum Binder Content (%)	5% - 8%	6.0	6.0
Stability (KN)	>3.5	12.63	13.86
Flow (mm)	2mm – 4mm	3.4mm	3.2mm
VTM (%)	3% - 4%	4%	5.2%
VFA (%)	75% - 82%	75%	72.74%
Bulk Density	-	2.398	2.387

The result obtained showed that the Asphalt mixture prepared using stone dust filler at Optimum Binder Content (OBC) met the requirement stated by the Federal Ministry of Works and Housing, while for the Asphalt mixture with HDPE Plastic as additive met the requirements with the exception of voids in total mix and voids filled with asphalt. Both asphalt mixture met the requirement for stability.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

After analyzing the current research and literature on asphalt mix design for hot mix asphalt containing plastic waste, it is clear that the use of plastic waste in HMA has the potential to improve the performance and sustainability of asphalt pavements. This is because the addition of plastic waste, as a binder modifier, can increase the resistance to moisture damage, improve the ductility and flexibility of the asphalt mix, and reduce the aging and cracking of the pavement.

However, the optimal dosage and type of plastic waste to be used in HMA is dependent on various factors such as the type of plastic waste, mixing temperature, mixing time, and the properties of the asphalt binder. Therefore, more research needs to be conducted to determine the effect of each factor and develop a standardized procedure for the use of plastic waste in HMA.

The results of the laboratory study suggest that the use of HDPE plastic waste in HMA mix design is feasible and can improve the mechanical properties of the asphalt. However, further research is needed to determine the optimal amount of HDPE plastic waste that can be added to HMA without compromising performance. In addition, the long term durability and environmental impact of using plastic waste in HMA should be considered. Overall the reuse of plastic waste in HMA has the potential to provide a sustainable solution to reduce plastic waste and improve the performance of road construction materials.

5.2 Recommendation

1. Identify the type and percentage of plastic waste: In this project, it is crucial to determine the type and amount of plastic waste that will be added to the asphalt mix. Different plastic waste have different properties, and the percentage added can also affect the performance of the asphalt mix. Therefore, conducting a thorough analysis of the plastic waste is essential.

2. Conduct Tests: Before developing the asphalt mix, it’s necessary to conduct several laboratory tests, such as Marshall Stability, Indirect Tensile Strength, and Dynamic Modulus, to determine the properties of the mix. These tests can help you understand the strength, stiffness, durability, and fatigue resistance of the mix.

3. Develop the Mix Design: After evaluating the plastic waste and conducting laboratory tests, it’s time to develop the asphalt mix design. You can use software programs such as Superpave software, which can help you select the aggregate gradation and determine the optimum asphalt content.

4. Consider Environmental and Economic Factors: One of the primary objectives of this project is to reduce plastic waste’s negative impact on the environment while keeping costs low. Therefore, it’s essential to consider environmental and economic factors when developing the asphalt mix design, such as the availability and cost of the plastic waste, and its effect on the environment.

5. Conduct Field Tests: Once the asphalt mix is developed, it is essential to test it in the field to determine if it meets the project's goals. Field tests, can provide valuable information about the mix's durability and resistance to damage caused by traffic and weather.

6. Monitor and Evaluate: Finally, after the asphalt mix is laid, it's crucial to monitor and evaluate its performance periodically. Collecting information on the mix's performance overtime can help you improve the design for future projects and provide useful insights into using plastic waste in asphalt mixes.

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APPENDIX

AGGREGATE CRUSHING VALUE TEST RESULT

Sample No	**Weight in Mould(g)**	**Weight passing 2.36mm sieve**	**Aggregate crushing value**
A	3798.5	695.2	18.3
B	3962.6	710.5	17.9
C	3872.8	723.1	18.7
AVERAGE			18.3

Aggregate Crushing Value (AVC) = $\frac{aveage\ weight\ passing\ 2.36mm\ sieve}{aveage\ weight\ before\ crushing} \times \frac{100}{1}$

AVC for sample A = $\frac{695.2}{3798.5} \times \frac{100}{1}$ =18.3%

AVC for sample B =$\frac{710.5}{3962.6} \times \frac{100}{1}$ = 17.9%

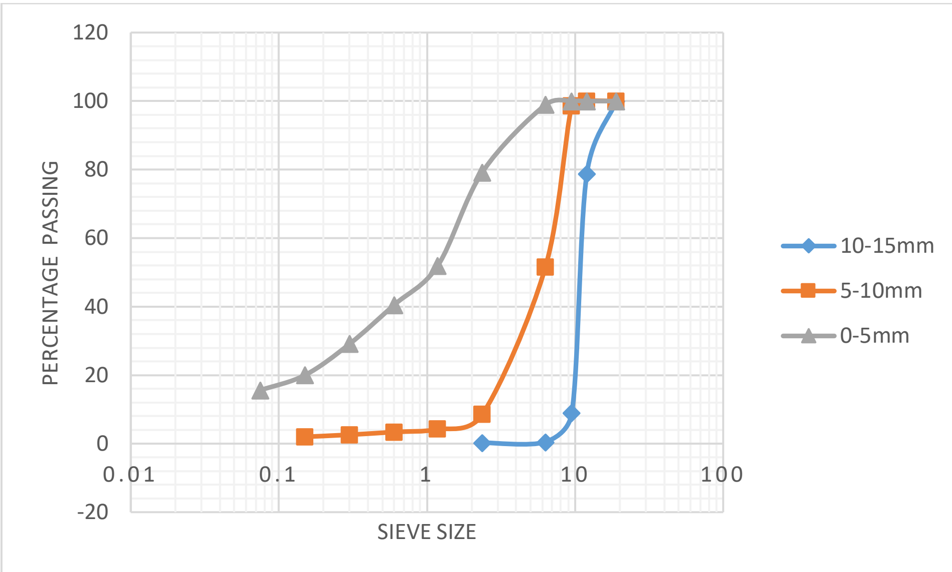
AVC for sample C = $\frac{723.1}{3872.8} \times \frac{100}{1}$ = 18.7%

Average = $\frac{18.3+17.9+18.7}{3}$ = 18.3%

SIEVE ANALYSIS TEST

Sieve sizes mm	**(10-15)mm**		**(5-10)mm**		**(0-5)mm**		**Combined mix**	**Specifications**	
	Percent passing	**15.0%**	**Percent passing**	**12.0%**	**Percent passing**	**73.0%**	**100**	**LL(%)**	**UL(%)**
19.0	100	15	100	12	100	73	100	100	100
12.0	78.8	11.8	100	12	100	73	96.8	85	100
9.5	8.9	1.3	98.6	11.8	100	73	86.1	75	92
6.3	0.5		51.5	6.18	98.9	72.2	78.4	65	82
2.36	0.3		8.5	1.02	79.2	57.8	58.8	50	65
1.18			4.2	0.5	51.9	37.9	38.4	36	51
0.600			3.4	0.4	40.5	29.6	30.0	26	40
0.300			2.6		29.1	21.2	23.8	18	30
0.150			2.0		20.0	14.6	16.6	13	24

0.075					15.6	11.4	11.4	7	14



Representation of the particle size distribution.

BITUMEN PENETRATION TEST

25 Degrees temperature was maintained for the test.

Number of penetration	Bitumen Cup 1	Bitumen Cup 2
1	64mm	65mm
2	64mm	62mm
3	63mm	64mm
Penetration	63.6mm	63.6mm
Average	64	

MARSHALL STABILITY TEST

Binder	Bulk density (g/cm^3)	VTM (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
2.0	2.248	10.73	23.80	55.04	11.08	2.4
4.0	2.282	9.37	22.67	58.62	14.24	3.1
6.0	2.387	5.20	19.11	72.74	13.86	3.2
8.0	2.312	4.40	21.66	62.19	13.11	3.4
10	2.301	3.50	24.50	52.94	10.92	3.6