A Comparative Experimental Investigation on the Performances of Waste Plastic Modified Hot Mix Asphalt in Dry and Wet Processes

Bikss Tesfa Getahun

A Thesis submitted to the Department of Civil Engineering

College of Civil Engineering and Architecture

Presented in partial Fulfillment of the Requirements of Masters of Science in Civil Engineering (Specialization in Construction Engineering and management)

Office of Graduate Studies

Adama Science and Technology University

May, 2025

Adama, Ethiopia

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Co-Advisor: Zerihun Mamo [MSc]

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DECLARATION

I hereby declare that this Master thesis entitled "**A comparative Experimental Investigation on the Performances of Waste Plastic Modified Hot Mix Asphalt in Dry and Wet Processes**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of Materials that are used for this thesis have been duly acknowledged through citation.

Bikss Tesfa Getahun

Name of student	Signature	Date

RECOMMENDATION OF THE ADVISORS

We the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled “A **Comparative Experimental investigation on the Performances of Waste Plastic Modified Hot Mix Asphalt in Dry and Wet Processes**” prepared under our guidance by Bikss Tesfa Getahun submitted in partial fulfillment of the requirement for the degree of Masters of science in Civil Engineering and Management. Therefore we recommended the submission of revised version of the thesis to the department following the applicable procedures.

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APPROVAL PAGE OF M.S.C THESIS

We, the advisors of the thesis entitled "**A comparative Experimental investigation on the performances Waste plastic modified Hot Mix Asphalt in Dry and Wet Processes**" developed by Bikss Tesfa Getahun, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately in to the final version of the thesis.

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APPROVAL OF BOARD OF REVIEWERS

We the undersigned, members of the board of Examiners of the thesis by **Bikss Tesfa Getahun** have read and evaluated the thesis entitled "**A Comparative Experimental Investigation on the Performances of Waste Plastic Modified Hot Mix Asphalt in Dry and Wet Processes**" and examined the candidate during open defense. This is, therefore to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering and Management

Chairperson	Signature	Date
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Final Approval and Acceptance of the thesis is contingent up on submission of its final copy to the office of post graduate studies (OPGS) through the department graduate council (DGC) and College graduate committee (SGC)

Department Head	Signature	Date
College Dean	Signature	Date
Office of post graduate studies, Dean	Signature	Date

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ACRONYMS

ASTM	American society for Testing and Materials
AASHTO	American Association of state High way Transport officials
AC	Asphalt concrete
ACV	Aggregate crushing value
BS	British Standards
GMB	Bulk specific gravity of asphalt mix
GMM	Maximum theoretical density of the Asphalt mix
VA	Air void
VMA	Voids filled by mineral aggregate
VFA	Voids filled by asphalt
ERA	Ethiopian Roads Authority
Gse	Specific gravity of the aggregate
OBC	Optimum bitumen content of the mix design
OPC	Optimum plastic content
HMA	Hot Mix Asphalt
MS-2	Marshall Mix Design manual -2
ITS	Indirect Tensile Strength
JMF	job mix Formula
PET	Polyethyleneterhaphlte
SSD	Saturated surface dry
TSR	Tensile strength ratio
Gsa	Apparent specific gravity of the aggregate
Gsb	Bulk specific gravity of the aggregate
Gb	Specific gravity of the bitumen

ABSTRACT

Virgin bitumen as a binder is very costly and also needs an improvement in pavement performance due to an ever-growing traffic. Plastic-modified binder application for hot mix asphalt is the way to solve this problem by dry and wet modification processes. Here the main gap is comparative study and the application of an optimized modifier process. Therefore the objective of the current study was to establish a comparative experimental investigation on the performance of waste plastic-modified hot mix asphalt in dry and wet processes. Here, to compare the performances of dry and wet processes, material tests, Marshall properties, rut resistance and moisture sensitivity performance evaluation, multi-criteria decision analysis (technique for order of preference by similarity to ideal solution), and simple cost comparison are applied using optimum plastic contents for dry and wet as 14.3 % and 2%, respectively. Based on the above approaches the result of aggregate tests (specific gravity, water absorption, aggregate crushing value, flakiness index and soundness for fine and coarse aggregate) are 2.517, 1.58%, 13.3 %, 16.45 %, 3.04 % and 5.08 % respectively. The results of the bitumen test (specific gravity, ductility, penetration and softening point) are 1.024 g/cm³, 125 cm, 64.35 and 50.1ºc. The stability, flow, bulk specific gravity, voids filled by mineral, voids filled by air, and voids filled by asphalt of the dry process are 21.26 KN, 2.35mm, 2.207 g/cm³, 16.69 %, 4.94 %, and 70.39 %, and the wet process is 16.42 KN, 2.47 mm, 2.199 g/cm³, 17.01 %, 4.85 %, and 71.53 %, respectively. For dry process, rutting depth and wheel tracking rate are 1.31 mm and 0.000065 mm/pass and for that of wet are 2.39 mm and 0.00012 mm/pass, respectively. Again, the closeness coefficient for dry is 0.97 and for wet is 0.487. The cost reduction found in the dry processes is 7.831 % and 1.05 % for that of wet from the conventional. Therefore dry process is attractive as well as selective for its performance and cost effectiveness.

Key words: Cost Comparison, conventional mix, dry process, optimization, waste plastic modified HMA, wet process

CHAPTER ONE

INTRODUCTION

1.1 Back ground of the study

A country's social and economic development depends heavily on its transportation infrastructure. The purpose of roads is to offer robust and long-lasting pavements that improve riding comfort and safety while lowering maintenance expenses. This can be accomplished by designing a good structural pavement as well as a proper asphalt composition. Over the years, several studies have been undertaken to improve asphalt mixture design for better performing pavements (Ramia Alajarmeh, 2018). In developing countries, roads make a crucial contribution to economic development and bring important social benefits by connecting one place to another place. In Ethiopia, road transport is the biggest mode of transportation and most roads are constructed with bituminous flexible pavement, allocating a large portion of the annual budget. Flexible pavement is often made out of asphalt concrete mixtures laid on granular base layers supported by compacted soil foundation. Asphalt concrete mixtures are typically constructed to have desirable features such as resistance to permanent deformation, fatigue resistance, moisture resistance, low-temperature cracking, skid resistance, and workability in order to provide safe and long-lasting flexible pavement. Asphalt binder has a significant impact on hot mix asphalt performance; its viscoelastic behavior contributes an essential role in the performance of asphalt mixtures (TANDEM, 2021). Therefore, conventional flexible pavement designs should need to improve their appreciable pavement performance by incorporating compatible construction materials like plastic as a bitumen binder modifier, nano clay, reclaimed asphalt materials, and waste ceramics & marbles as a partial replacement of aggregate.

Polymers are employed all over the world for their unique features, such as low weight and chemical resistance, but they offer an environmental concern since they require so many years to degrade when buried in landfills. Bitumen has the second largest environmental impact in road construction (Lastra-González et al., 2020) . Filler in asphalt concrete is one of the few applications for post-consumer waste plastics that may meet both of these requirements. If waste plastics in asphalt concrete were ~10%, this application could employ all plastic trash produced globally and it is noble to consume waste plastic (Grady, 2021). Plastic materials, applied for asphalt pavement modification can be categorized into thermosetting polymers and thermoplastic polymers. The thermosetting polymers are cured during heating, resulting in a polymer matrix that is easy to reprocess, making it a reversible process. The thermoplastic polymers can be sculpted and designed into new shapes via heat. The thermoplastic polymers consist of polyethylene terephthalate (PTP), polypropylene, polystyrene, low-density polyethylene, and high-density polyethylene (El-Naga et al.,019). The bottles used to bottle water are usually made of polyethylene terephthalate (PET). They are inexpensive and durable, therefore they appeal to the lower to middle classes. When emptied, the bottles are frequently thrown away indiscriminately, becoming a significant threat to the environment (Adedayo A. Badejo1 et al., 2017). In this study, therefore a waste plastic of thermoplastic polyethylene terephthalate (PET) was used. Hence, the virgin bitumen is modified by this type of plastic (PET) to achieve better performance from the conventional asphalt mix. There are two types of processes to modify the neat bitumen. So the virgin bitumen is modified by plastic (PET) to evaluate the performance of dry and wet processes, keeping the conventional mix as the control point. During the wet process, the plastic (PET) and the selected penetration grade bitumen are mixed before mixing with hot aggregate vigorously. Whereas in the dry process the plastic is mixed with the heated aggregate before mixing with the bitumen. Mixing plastic with bitumen boosts the bitumen's capacity to resist high temperatures. The plastic trash is melted and combined with bitumen in a specific ratio. Normally, blending occurs when the temperature reaches 45.5°C, however when plastic is blended, it remains stable at 55°C. The rigorous laboratory testing verified that the bituminous concrete mixes generated using the modified bitumen binder fulfilled all of the set Marshall mix design criteria for the surface course of road pavement (Nigussie, 2018). For the dry process, shredded plastic is added to heated stone aggregate at 170oC and combined with hot bitumen at 160oC. This procedure increases the aggregate's quality in terms of voids, moisture absorption, and soundness by coating it with polymers (TANDEM, 2021).

A limitation was observed in a comparative study of performance of dry and wet processes. Therefore, establishing a comparative Experimental investigation performance for dry and wet processes was found interested in optimization, minimizing of assumption issue and binder cost comparison of dry and wet processes.

1.2 Statement of the problem

Many of the studies before this were conducted on the evaluation of asphalt performance on conventional and plastic waste-modified asphalt mix by wet process as well as dry process. And some others investigated the performance comparison of conventional with wet and dry processed waste plastic modified asphalt mix. Material characterization should give attention in the mix design. Here is the material should be characterized first to see whether they can fulfill the requirements specified, and the tool is based on the idea that there is an important aggregate structure responsible for absorbing and transferring stress without resulting unrecoverable deformation (Ferreira et al., 2020). Basically, different additives are available, which can be added directly into the bitumen, i.e., wet process, as a binder modifier, or blended directly with the aggregates which is dry process (TADEM, 2021). Marshall Stability analysis was performed in the wet process and concluded that PET modified bitumen has higher stability than conventional bitumen .with up to 3.5% polymer content addition, however the marshal flow value decreases (Abiyot Mihret et al., 2018). Many other researchers compared the performance of asphalt as rutting resistance and moisture sensitivity and they also assumed the marshal properties of the dry and wet processes were nearly the same or insignificant differences without any result comparison. But in this study, in addition to rutting resistance and moisture sensitivity as a function of wheel tracking test and indirect tensile strength, there is also the determination of Marshall Properties of both dry and wet processed plastic waste-modified asphalt mix to arrive at the sound decision. Many times the dry process is selected rather than the wet process in the absence of a comparison study. Therefore, optimization of the performance of the two processes is needed to select one from the two. The ideal fiber selection is a highly difficult task that must consider a wide variety of criteria and alternatives. Decision support systems have been used in the construction industry, but it fails to pick fibers for bituminous mixtures. To address this gap, TOPSIS and one other Multi-Criteria Decision-Making Analysis approaches for selecting the best fiber to be used in asphalt concretes are provided (Slebi-Acevedo & Castro-Fresno, 2019). Even the cost comparison usually held with the conventional one. In this study a comparison of the wet and dry process costs is held. The cost of waste plastics is Rs.7 per kilogram. Processing costs Rs.5 per kilogram. The total cost of waste plastics is Rs.12 per kilogram. According to test results, the optimal percentage of plastic in the blend is around 8% by Wt. of bitumen). Roads in India are often built with a width of 3.0 m, 3.75 m, or 4.0 m. For example, a 1 km road with a width of 3.75 m requires approximately 21300 kg of bitumen. For new work and 11925 Kg, the total cost of waste plastic used in road employing mix technique is Rs.76,700 (Akshar Patel et al., 2018). So this study addressed the above hypothesis through experiment.

1.3 Research Questions

The following questions have to be addressed in this study.

1. What are the characteristics of materials used in hot mix asphalt?
2. What are the advantages of modifying the conventional hot mix asphalt with waste plastic by dry and wet processes?
3. How to compare the performances of dry and wet processes?
4. How is the cost comparison between dry and wet processes?

1.4 Objective of the Study

1.4.1 General objective

The main objective of this study is to conduct a comparative Experimental Investigation on the Performance of waste plastic modified Hot Mix Asphalt in Dry and Wet processes.

1.4.2 Specific objectives

1. To assess the materials characteristics used in the hot mix asphalt

2. To evaluate the performance of waste plastic modified hot mix asphalt using both dry and wet processes

3. To optimize the dry and wet processes by multi- criteria decision analysis method.

4. To compare the costs associated with the dry and wet processes

1.5 Scope of the study

The performance of dry and wet processes of plastic-modified asphalt mix is evaluated in this study. The performance of the two processes is then compared by partially substituting plastic waste (PET) for virgin bitumen. Marshal Mix design for conventional mix is performed to have a reference mix. Optimum plastic content of these processes is determined by the weight of optimum bitumen content (OBC) of the conventional asphalt mix. Trials for dry and wet processes are based on the time limit. Particularly, for any air void increase additional compaction is implemented from the conventional to attain the required void content. In this study, rutting resistance performance, moisture sensitivity and Marshall Properties of the wet and dry processes are evaluated. Material characterization for hot mix asphalt, performance evaluation, optimization and cost comparison of dry and wet processed modified mix are also incorporated. Even though different penetration grade bitumen are available, for this study only 60/70 grade bitumen was assigned. Softening point, penetration, ductility and specific gravity quality tests of this bitumen are conducted. Aggregates of different classes are A constitutes of the mix such as coarse aggregate, fine aggregate and filler. The following engineering properties of the aggregate is tested; particle Size distribution/gradation, flakiness index, specific gravity, water absorption, aggregate crushing value (ACV), Soundness. This study also limits to surface or wearing course of the flexible asphalt pavement road. The experimental test is conducted in different laboratories; for example plastic preparation, cleaning and grinding to its required size is at Tatek, Rahel and Guadegnochachew hibret sira mahiber (Addis Ababa), the Marshall stability, flow and volumetric properties from Bulbla-Alage design and build Asphalt road project (Bulbula) and Not only this but also rutting resistance performance and moisture sensitivity of the mix is done in the Central Laboratory of Modjo-Hawassa design and build high way project. Waste plastic, particularly (PET) is applied for this research.

1.6 Significance of the study

The current study directs the Ethiopian road administration to use waste plastic-modified asphalt concrete for flexible pavement road construction throughout the country. By incorporating waste plastics into road construction as a partial replacement for bitumen, the construction industry gets improved performance modified mix relative to the conventional which is an interesting practice. Plastics are non-biodegradable within a short period of time for burying of them. On the other hand when it burns, emissions from it pollute the environment. This study therefore has a vital role in decreasing the amount of waste plastics disposed in the environment by recycling it for the asphalt road construction. Bitumen is very expensive material when compared to the waste plastics since the plastic is already waste and hence when replacing the bitumen partially with the waste plastic, the cost for the road is now preserved and the economic benefit is magnified. A comparative performance investigation of this research helps in the selection of a better performance process. Even the cost analysis is discussed in this study on both dry and wet processes to compare them.

1.7 Organizational structure of the study

This section shows the graphical outline of this study. Figure 1.1 below shows the organizational structure of the study

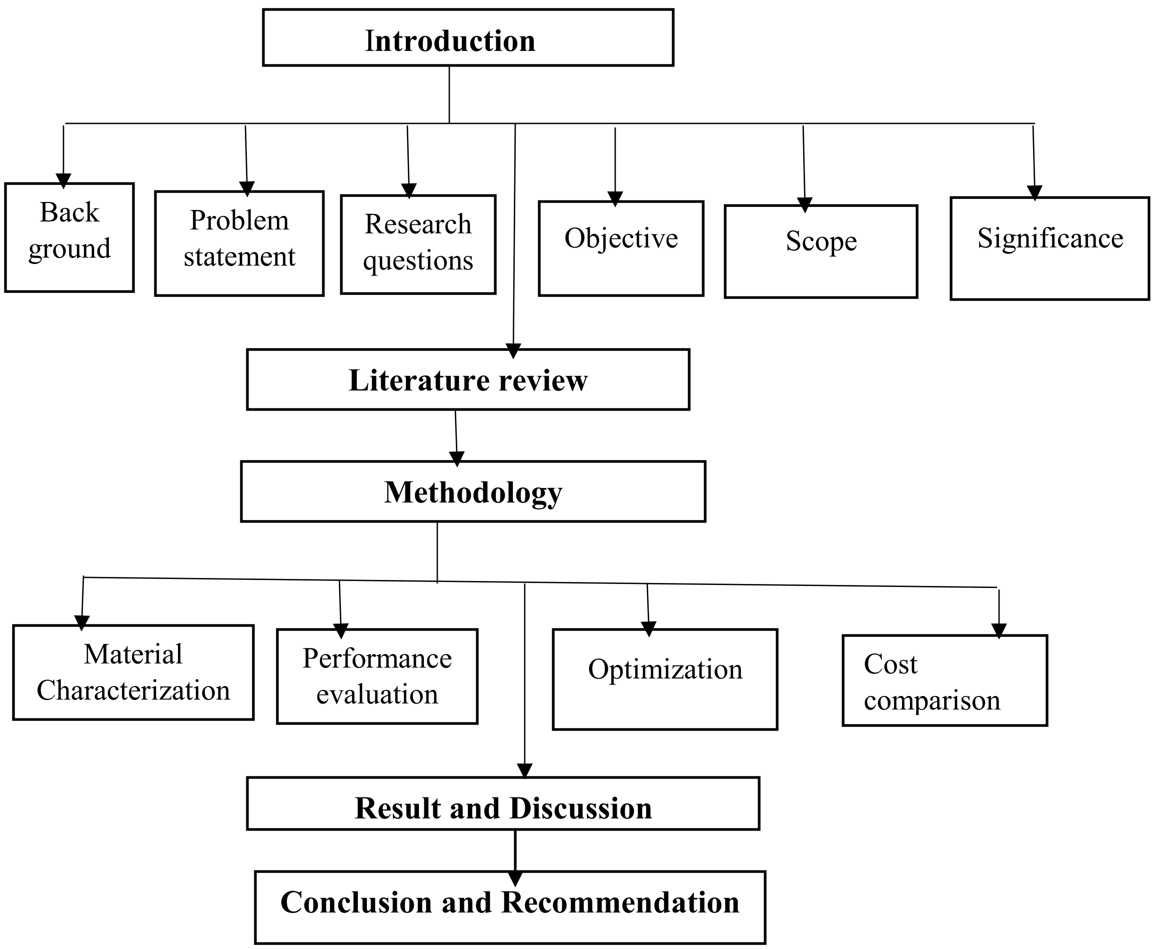

Figure 1.1 organizational structure of the study

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter covers a review of the existing literature that relates to this study. The literature helped to give the basic information about this research. Many of the studies are the expansion of the existing studies. An attempt is made as much as possible that the literature reviewed here is on Google Scholar and published in reputable journals instead of simply on the traditional Google, except for a few thesis that narrate around this area. Reviewing the literature is done on the following areas to find the desirable information during the course of conducting this study, like desirable properties of asphalt aggregates, bitumen, fillers that can be added in the hot mix asphalt design, plastics, performance evaluation of waste plastic modified asphalt mix in dry process and performance evaluation of waste plastic modified asphalt mix in wet process.

2.2 Desirable Properties of Asphalt Aggregate

The study proposes a simple tool for evaluating the quality of particle size distribution and its ability to develop rutting-resistant asphalt mixes. The tool is based on the concept that there is a main aggregate structure capable of absorbing and distributing loads while avoiding plastic deformation. This investigation presented two parameters to characterize such a structure: the $\propto$ and C ratios. The first characterizes the degree of interlocking of this structure, called the Dominant Aggregate Size Range (DASR), while the latter is connected to the proportion of relatively larger particles inside this structure (Ferreira et al., 2020). Nevertheless, this concept has been broadly used for aggregate type's selection. For example, limestone and basalt as basic aggregates has been widely used for the construction of asphalt pavement surface layers in China for their appreciable specific gravity (Fucheng Guo et al., 2020). The statistical studies revealed an important relationship between the two compaction parameters as response factors and the three gradation parameters as explanatory variables. These relationships were applied to calculate the best possible aggregate gradation in terms of asphalt mixture compatibility and rutting performance (M. Reza Pouranian & John E. Haddock, 2020). Existing studies has demonstrated that aggregate structure in asphalt mixtures is affected by the parameters, like aggregate size distribution, aggregate morphological features (shape and surface macro-texture), compaction method, compaction effort, and asphalt mixture lift thickness (Haddock, 2019). Aggregates in SMA should withstand degradation (fracture and abrasion) under ultimate stresses at the subjected points. The current approaches for asphalt mix design and acceptance testing rely on volumetric properties. Vital to the calculation of mix volumetric properties are specific gravity measurements of the mixture and the mixture's aggregate (Esat Gashi, 2017). Over the last four decades, researchers have studied the impact of aggregate properties on the mechanical properties of hot mix asphalt (HMA). Automated techniques can now measure shape, texture, and angularity with greater precision than conventional approaches. Other elements to consider include aggregate type and gradation, as well as the effects of blending (Behiry, 2015). Whatever any type of aggregate, recycled aggregates produced from homogeneous marble and andesite quarry wastes in Afyonkarahisar–Iscehisar region were compared to two other aggregate specimens for that time used in Afyonkarahisar city asphalt pavements. Los Angeles abrasion, aggregate impact value, freezing and thawing, flakiness index for aggregate specimens and Marshall Stability flow tests were carried out. The test results should also revealed that the physical properties of the aggregates are within specified limits (Hu¨seyin Akbulut, 2006). Even though, RCA is totally defined as a rough, porous, flat and irregular material, but for unique, it is characterized by lower bulk and specific gravity, and a significantly higher water absorption, which leads to poor mechanical properties (Hanaa Khaleel et al., 2018). The favorability of aggregates incorporated in asphaltic mixtures is, from their physical and mechanical properties perspective. The physical properties of aggregates are gradation, particle shape, surface texture, durability, cleanliness, toughness, and absorption. These properties firstly determines the performance of mixtures. The proper quantification of aggregate geometric irregularities is important to recognize their effects on pavement performance (Hattatoglu & Akbuluta, 2013). The form, angularity, and surface roughness of aggregates have a significant impact on how well hot-mix asphalt (HMA) performs. Particle interlock is affected by aggregate angularity and shape, which are related to rutting. An aggregate's rough surface roughness can reduce fatigue cracking and enhance the aggregate-binder interaction (Bessa et al., 2014). Among four aggregate shapes evaluated, the cubical aggregate indicated the best rutting resistance. Flaky and elongated aggregate was shown to have lower performance and higher breakage. Cubical particles were important for increased aggregate interlocking and improved rutting resistance (Jian-Shiuh Chen et al., 2013). Strength and form have a major impact on the asphalt mixture's ISS, shown by the great relation between the crushing value, loss-angles value, roundness, and flakiness index and contact characteristics. The internal structural index and the Marshall, rutting, and bending stiffness modulus data show that aggregate contact qualities have a direct impact on the asphalt mixture's performance at different temperatures (Hafiz Muhammad Zahid Hassan & Cai, 2021). A Large portion of the pavement structure is comprised of aggregates. The aggregates' engineering qualities, shape (i.e., form and angularity), and texture have a major effect on the pavement's overall performance (N et al., 2014).

2.3 Bitumen

Originally used as mortar and other materials, bitumen was a type of mineral pitch that was found in Palestine and Babylon. Bitumen Judaicum, mineral pitch, asphalt, and Jew's pitch are all equivalent. Additionally, it offers the more scientific meaning that follows: "In contemporary scientific usage, the generic term of some flammable compounds, native hydrocarbons that are more or less oxygenated, liquid, semi-solid, and solid, such as naphtha, petroleum, asphalt, etc. Elastic Bitumen: Elaterite or Caoutchouc Mineral (Rajagopal, 2003). There have been several approaches developed for bitumen and heavy oils that rely on solubility and adsorption. The most frequent standard approach used in the petroleum industry for separating heavy oils into compound classes is SARA (saturates, aromatics, resins, and asphaltenes) analysis (Gentzis, 2000). Even though the bitumen is a tiny component of the asphalt, it performs the most significant role in providing consistency to the HMA material, which is required for practical purposes: even minor variations in the bitumen can affect the overall qualities of asphalt. Although the use of asphalt can be traced back to the qualities of its bitumen (Loise et al., 2019). Bitumen is the residue left behind from crude oil distillation. Bitumen is utilized in over 200 applications, the majority of which are related to civil engineering, especially paving and roofing. Bitumen is often modified with an elastomer, a plastomer, a thermoset, sulfur, or a mineral acid in order to improve its properties and enhance its performance (Masson et al., 2008). Basically, bitumen is now described as a "virtually involatile, adhesive and waterproofing material that came from crude petroleum, or present in natural asphalt, which is completely or nearly completely soluble in toluene, and very viscous or nearly solid at atmospheric temperatures" in the recent European specifications (Lesueur, 2008). The basics Solid bitumen's physical features include solubility, density, and porosity, while its chemical properties are discussed in terms of elemental ranges based on the final examination of a large number of solid bitumen samples. The sample set has carbon content ranging from 72 to 93%, hydrogen from 2 to 7%, and nitrogen from < 0.1% to 5%. The oxygen content is normally below 1%, while the sulfur content ranges from <0.1% to 8%. Insoluble (and more mature) solid bitumen's (impsonites) have less elemental diversity than soluble solid bitumen (Maria Mastalerz et al., 2018). The study tested three types of rejuvenators. Rheological testing on bitumen include softening point, penetration, and complex shear modulus. The tests were conducted in three stages: no-aging, RTFOT (Rolling Thin Film Oven Test) aging, and combined RTFOT and PAV (Pressure Aging Vessel) aging. It was demonstrated that virgin bitumen ages more slowly than renewed bitumen. There was no significant difference in the aging behavior of bitumen mixed with different types of rejuvenators (Ongel et al., 2015). Bitumen, a petroleum-derived black viscous thermoplastic substance, is widely utilized in road construction and waterproofing systems due to its outstanding adhesive and water barrier qualities. Bitumen production consists of the separation of the light fractions of crude oil by distillation and supporting processes, such as solvent extractions and finally air-blowing oxidation whenever required to fulfill product criteria (Varanda et al., 2017).

2.4 Filler and its Application in Hot Mix Asphalt concrete

Aggregates bigger than 4.75 mm are considered coarse, whereas aggregates smaller than 4.75 mm are considered fine and Fillers are aggregate particles smaller than 75 µm in size. Although the filler particles are modest in size, it is well recognized that the filler has an important impact on the properties and performance of the asphalt-concrete mixture (Zulkati et al., 2012). The asphalt binder and mineral fillers together has a considerable impact on asphalt mixtures and pavements, because 90% of the total surface area in the mixture comes from the filler (Tan, 2019). Filler's influence on asphalt is governed by five important properties: (1) size and size distribution, (2) shape, (3) texture, (4) surface area, and (5) void content (Bahia, 2010). Mineral filler used in asphalt mixtures is comprised of fine-grained mineral particles that are either naturally present in the aggregate system or supplied independently. It has frequently been defined as the portion of aggregates passing through a 0.075 mm screen and is also referred to as mineral dust or rock dust (Yu Chen et al., 2020). The impact of filler on the properties of HMA mixes was also examined. The parameters of HMA mixtures tested include optimum asphalt cement (AC) content, indirect tensile (IDT) strength, toughness index (TI), tensile strength ratio (TSR), and APA rut depth. The findings indicated that fillers had a substantial effect on the characteristics of HMA mixes. Some of HMA's qualities improved as the filler content increased, whereas others declined. The amount of Filler for mix design should be determined by the overall performance of HMA mixtures (BAOSHAN HUANG et al., 2006). The primary goal of this study is to investigate the effect of non-conventional fillers such as non-plastic sand, brick dust, and ash as filler replacements on the performance of asphalt-concrete mixtures, as well as to compare the characteristics of asphalt-concrete mixtures to conventional ones using the AASHTO test procedure. The experimental data show that using non-plastic sand offers a higher Marshall Stability value than other non-conventional filler materials (Sobhan, 2013). Asphalt concrete pavements account for approximately 90% of China's highways. The building and maintenance of these pavements require a large amount of aggregates and mineral fillers, which usually account for almost 95% of the asphalt concrete. The filler is an essential component of the aggregates used in asphalt mixes. The presence of it has a significant impact on the qualities of mixtures based on its features (M. Chen et al., 2011). Seven asphalts, three different mineral fillers added in varying quantities, and six aggregates were tested. The analysis was carried out in terms of energy parameters calculated using the SFE components of the materials tested. Corresponding data revealed that the addition of filler in the asphalt caused changes in the resistance to both fracture and moisture damage of the mastic-aggregate systems, as well as the moisturization of the mastic over the aggregate as measured in terms of energy parameters (Alvarez et al., 2012).

2.5 Plastics

Plastics are polymers, and the clear definition of a polymer is something comprised of several units. Polymers are nests of molecules. Each bond in the chain frequently consists of carbon, hydrogen, oxygen, and/or silicon. To build the chain, numerous links are hooked or polymerized together. Polymers are formed by heating petroleum and other materials under regulated conditions and breaking them down into smaller molecules known as monomers. These monomers are the constitute elements of polymers (Halden, 2010). Till the mid-1950s, the European plastics industry's primary raw material source was coal. Coal undergoes destructive distillation to produce four products: coal tar, coke, coal gas, and ammonia. Coal tar was a major source of aromatic substances like benzene, toluene, phenol, naphthalene, and related products (Gilbert, 2017). Plastics are malleable materials that can be molded into solid objects of different sizes and forms. The International Union of Pure and Applied Chemistry (IUPAC) defines plastics as a representative word for "polymeric materials that may contain other substances to enhance performance and/or minimize costs (João Pinto da Costa et al., 2016). Each session will cover a variety of chemical processes for upcycling plastic waste, such as hydrogenolysis, photocatalysis, pyrolysis, and solvolysis, in order to convert various plastic feedstock's into value-added chemicals, materials, or fuels (Xi Chen & Zhang, 2021). Plastics recycling is clearly a solution to the plastic pollution challenge. Medical plastic recycling is limited because to the difficulties associated with sorting and cleaning. Recycling medical plastic waste requires a wise coordination between the healthcare sector and the recycling industry (Joseph et al., 2021). Finally, all mixtures' static indirect tensile strength (IDT) was measured using the splitting tensile test. The optimum PWM content for improving the performance of asphalt mixtures has been found to be 7.43% by weight of OBC. It increased stability by 42.56%, flow by 89.91%, and strength by 13.54 % (H. Naghawi, 2018). Pyrolysis technology could provide an alternative method for upgrading plastic trash and reusing it. The thermal disintegration of plastic leftovers in an inert atmosphere and at moderate temperature and pressure (about 400°C and 3.5 MPa) milled their structure into smaller intermediate species (F. Pinto et al., 1998).

2.6 performance evaluation of waste plastic modified Hot mix Asphalt by dry process

The results demonstrated that both unmodified and modified polymers produced bituminous binders with improved viscosity and viscoelastic properties at medium-high in-service temperatures when compared to a reference sample (PMB45/80-65). The addition of plastic (and modified plastic) to AC asphalt mixes improves mix behavior in terms of water sensitivity and rutting resistance (Martin-Alfonsoa et al., 2019). As road traffic rises, so do the pressures forced on pavements, necessitating improvements to their structural and functional performance. The addition of polymers to bitumen or asphalt mixtures is one approach for enhancing the quality of flexible pavements. Although modifying bitumen with waste polymers might improve the properties of asphalt mixtures, using recycled plastic may also produce a similar effect with extra environmental benefits (Costa et al., 2013). The different parts of PET modified bitumen are assessed in two stages as unaged and aged conditions. The rutting, fatigue, and aging of bitumen binder were evaluated using dynamic shear rheometer (DSR), rolling thin film oven (RTFOT), and pressure aging vessel (PAV) experiments. The corresponding data's revealed that the optimal waste plastic content is 6-8% to improve rutting and aging resistance. Especially, 8% PET increases fatigue cracking resistance by showing a low fatigue factor(G sin d) (Mashaan et al., 2021). Four materials were assessed in this study that improves the composition of a conventional asphalt mixture. By dry process, PE, PP, PS and ELT were utilized to replace 1% of the filler fraction. After each mixture examined separately, it can then generalized that: Mixtures, ELT increases 30% the resistance against flow and 50% the stability compared to the conventional mixtures. The resulting mixture is with more elastic performance with a lower phase angle. PP and rubber has a very similar performance, being that polymeric waste the one that increases the stability of the reference mixture the most (60%), and exhibiting also the most elastic behavior; however, the increase of its resistance against plastic deformation (flow) is not statistically significant. PE is the polymeric waste which increases the resistance against plastic deformation of the traditional mixture the most (60%). This material also increases the stability of the asphalt mixture (60%) and its elastic performance as compared to the conventional mixture. Concerning PS, this is a different case because important differences in the results have been obtained (Lastra-González et al., 2016). The results of modified bitumen tests shown that the addition of this modifier decreased the penetration and increased the softening point of the modified binder. The results demonstrated that the addition of this modifier targeted to increase the strength of the asphalt mixtures. The optimized percentage of PTP giving the better performance of the asphalt mixtures is 12%. At last, the quantified benefits suggested that addition of 12% of PTP bumped the pavement service life 2.81 times and 20% decreased in the asphalt layer thickness (El-Naga et al., 2019). Two sizes of plastic scrap, course and fine, were considered. An AC16S semi-dense mixture was prepared for this task, with a 10% reduction in binder, 10% and 20% of plastic scrap binder added in coarse and fine sizes respectively. The Marshall stability and flow test findings demonstrated that, reduced moisture damage which is an increased indirect tensile strength (ITS), higher air void content, and a 2% reduction in the conserved tensile strength ratio while maintaining the same usage field as the conventional combination. Meanwhile, robust modulus and rutting tests revealed considerable decreases in plastic deformations as compared to conventional values (Movilla-Quesada et al., 2019). Not all but some of the measured parameters of the asphalt mixture with the modifier utilized in this investigation fell within the acceptable guideline ranges. Based on experimental results, it is determined that asphalt mixtures with waste polyethylene modifier up to 10% and waste PVC modifier up to 7.5% can be used for flexible pavement construction in regions that are hotter in terms of stability, stiffness, and voids characteristics (Md. Nobinur Rahman et al., 2013). The study demonstrates that a 14.4% partial replacement of bitumen with plastic waste improves the Marshall Properties of HMA and fully meets the performance standards of the Marshall Mix design. The OBC rutting depth is 4.56mm, with an indirect tensile strength ratio (TSR) of 0.798. Similarly, 3.3mm rutting depth and 0.832 TSR were obtained at OPC. This indicated that partial replacement of plastic waste highly improves the rutting and moisture resistance performance of conventional HMA mix (TADEM, 2021).

2.7 Performance Evaluation of Waste plastic modified Hot Mix Asphalt by Wet Process

The wet process was used to construct (0, 2.5, 5, 7.5, 10, 12.5, and 15 wt% asphalt binder). The physical and mechanical properties of unmodified and DWP-modified mixes were studied using the Marshall Stability, indirect tensile strength, and wheel track tests. According to the corresponding data, the presence of PET improves Marshall Stability while decreasing moisture susceptibility and rutting depth in modified mixtures compared to control mixes. But the highest results are found with optimized PET content of 7.5-10% DWP (Nasr, 2016). Due to the possible environmental benefits, the plastics and asphalt pavement sectors are becoming more interested in recycling waste plastics into asphalt. The wet process encourages mechanically mixing trashed plastics into the asphalt binder as polymer modifiers (Yin et al., 2021). Wheel tracking, moisture susceptibility, resilience modulus, and drain down tests were performed on mixes containing 0%, 2%, 4%, 6%, 8%, or 10% waste PET by weight of bitumen content. Experimentation demonstrated that the acceptable range for waste PET was 4-6% by weight of bitumen content. The results shown that the addition of waste PET into the mixture has a significant impact on the characterstics of SMA (Esmaeil Ahmadinia et al., 2012). For the first time, bulk specific gravity, Marshall test, indirect tensile stiffness modulus, and indirect tensile strength tests were established on mixtures with varying percentages of PET. Next to this, the plastic deformation of the PET-modified asphalt mixture was evaluated under static and dynamic loads. Finally, in the last stage, relationships were identified between the results found in the first and second steps. It was that for high plastic content, the rutting qualities of asphalt mixture may significantly enhance when exposed to dynamic loading conditions (Moghaddam et al., 2014). In this investigation, wet process technology is applied, which can handle up to 8% plastic content. Another dry process technology can be applied to modify bitumen with more than 8% plastic content. It is better , if the interesting researcher focus on the dry process to use more plastic (Abiyot Mihret et al., 2018).

2.8 Research Gaps

Many gaps from a wide range of publications are noted. According to these investigations, almost all of the gaps discovered in various studies have similar content, and the gaps in the studies are summarized in the following table. The interested researcher is guided to address these inadequacies in the field. The author, research title, results, and gaps are displayed in table 2.1 below. Various study titles can be created according to these gaps.

Table 2.1 Summary of existing study gaps

m. No.	Author & year	plastic type	Modification method	Research Title	Results	Research gaps
1	Martin-Alfonsoa et al., 2019	Unmodified & Modified Plastics	Binder Modification	Use of plastic wastes from greenhouse in asphalt mixes manufactured by dry process	Enhanced viscous and viscoelastic properties at high temperatures. Improved water sensitivity and rutting resistance.	Long-term field performance evaluation of different plastic types and modification method
2	Costa et al., 2013	Virgin Polymers & Recycled Plastics	Binder Modification	Incorporation of Waste Plastic in Asphalt Binders to Improve their Performance in the Pavement	Similar performance improvements as virgin polymers with environmental benefits	Life-cycle assessment considering environmental impacts of plastic waste collection, processing, and transportation
3	Mashaan & 2021	PET	Binder Modification	Investigating the engineering properties of asphalt binder modified with waste plastic polymer	Ideal PET content: 6-8% for improved rutting and aging resistance. 8% PET improves fatigue cracking resistance. Investigation of the impact of different PET sources.	Investigation of the impact of different PET sources (e.g., bottle grades, film grades) on binder performance.
4	Abiyot Mihret et al., 2018	Wet Process Technology (PET)	Applicable up to 8% plastic content	Improve the quality of bitumen using PET bottle plastic as an excellent additive	Improved performance compared to conventional asphalt	Further studies on dry process technology for >8% plastic content
5	Movilla-Quesada et al., 2019	Coarse & Fine Plastic Scrap	Binder Reduction (10%) & Plastic Scrap Addition (10% & 20%)	Use of plastic scrap in asphalt mixtures added by dry method as a partial substitute for bitumen	Reduced moisture damage. Increased indirect tensile strength. Decreased plastic deformation.	Micromechanical analysis of the interaction between plastic scrap and asphalt aggregates.
6	TADEM, 2021	Plastic Waste(PET)	Partial replacement of bitumen ~15%	performance evaluation of plastic waste modified hot mix asphalt concrete	Improved Marshall properties. Reduced rutting and improved moisture resistance	Investigation of plastic coated and non-coated aggregate
7	Slebi-Acevedo, C. J., et al. (2019)	Fiber	Reinforcement replacement	A multi-criteria decision-making analysis for the selection of fibres aimed at reinforcing asphalt concrete mixtures	Synthetic fibers proved to be a suitable option as did fibers with high tensile strength and elastic modulus	Selecting the effective fiber through multi-criteria decision analysis method (TOPSIS)

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

This study intended to offer a comparative experimental investigation on the performance of waste plastic modified hot mix asphalt using dry and wet processes. The characterization of Hot Mix Asphalt materials is a critical step in doing this research. During material characterization, techniques for basic material tests are discussed. Samples of desirable size aggregates are sampled from Bubula-Alage design and build asphalt road project crusher plant of kibish Construction, 60/70 grade bitumen also used and the plastic Waste (PET) for its cheapness and easily accessibility taken from Tatek, Rahel and Guadegnochachew Hibret sira Mahiber after collecting, Cleaning and shredded to the required size of (3-5) mm from Addis Ababa. Initially, Conventional Hot Mix asphalt mix design is used to determine the optimum plastic content for both wet and dry processes. Performances of conventional hot mix asphalt, such as the mix's bulk specific gravity, volumetric characteristics (air void, voids filled in mineral aggregate, and voids filled by asphalt), stability and flow were then ascertained. Many trials with different plastic (PET) content are carried out by weight of the optimum bitumen content of the control mix during the process of determining the optimal plastic content of the dry and wet processes.

After having optimum plastic content for each processes, Marshall Stability, flow, volumetric properties (Void in air, Voids filled by mineral aggregate and Voids filled by asphalt aggregate) and bulk specific gravity of the modified mixes are analyzed to check whether these properties of the modified mixes are fall in the limit set in the standard. In relation to this performance evaluation of waste plastic modified Hot Mix Asphalt of dry and wet processes of rutting in terms of wheel tracking rate and deformation (wheel tracking depth) and the moisture sensitivity by using Indirect tensile strength and TSR are analyzed. Later on optimization of the two processes and cost analysis is conducted.

3.2 Research organization

Immediately after sampling and preparation of bitumen, aggregate, filler, and plastic (PET), characterization is carried out. Gradation, specific gravity, water absorption, aggregate crushing value, flakiness, and soundness are among the tests used to determine whether an aggregate's characteristics can satisfy the standards set by ASTM, AASHTO, BS, and ERA. Regarding to bitumen, specific gravity, ductility, penetration and Softening point tests were established to meet the specifications set in the standards as the aggregate and the plastic is characterized in way for its cleanness and shredded to the recommended size and sieved.

After characterization of the Materials the conventional mix design of the hot mix Asphalt was performed to get optimum plastic content of dry and wet processes plastic modified Hot Mix Asphalt. Performance evaluation is done by combining plastic-coated aggregate and bitumen in a dry mix, and then by combining plastic-modified bitumen with aggregate in a wet mix. Later on optimization and cost comparison of the two processes were come. It is a graphical Sketch which helps to skim organization of this research step by step .the above steps were narrated through the figure 3.1 given below.

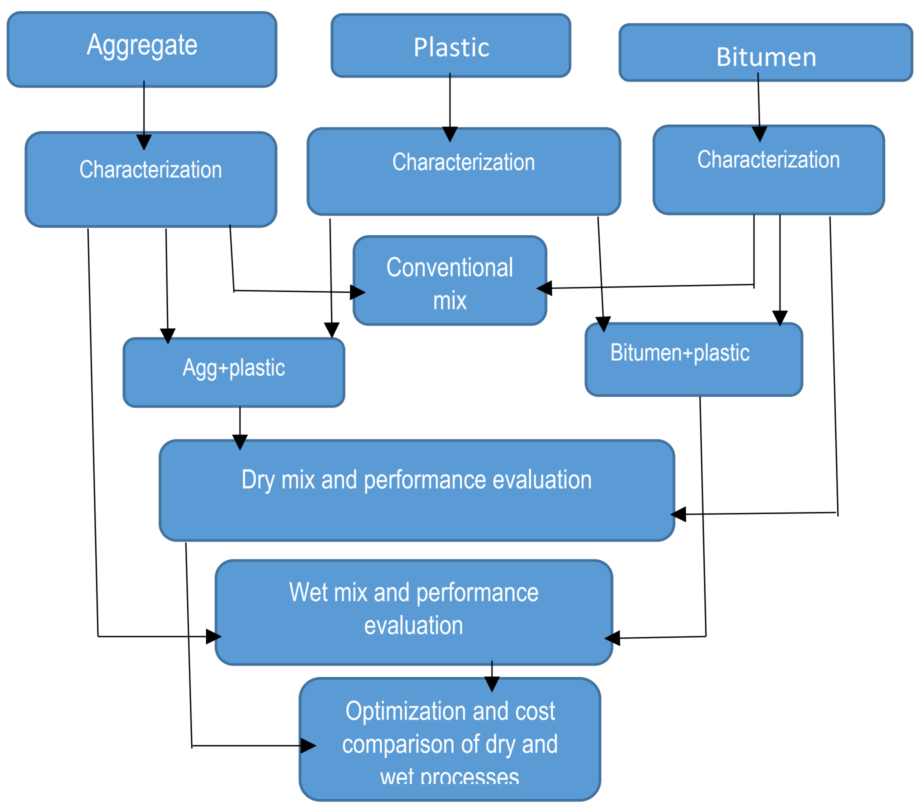

Figure 3.1 Research methodology organization

3.3 Materials

The constituents are what make up the hot mix asphalt's heterogeneous mixture. These consist of bitumen, filler, coarse, medium, and fine aggregate, as well as plastics for modification. Characterization is the basic component of these materials. It is meant to serve as a reminder to conduct certain tests. Tests based on international test techniques are frequently addressed for bitumen, aggregates, and waste plastic (PET) processing.

3.3.1 Aggregates

In the construction world aggregate refers to materials like sand, gravel, crushed stone or recycled concrete that are used in the production of concrete, asphalt or other construction materials. Therefore these aggregates are characterized for a particular use through testing. Testing types, procedures and test validity methods of the aggregates are here discussed under.

Sieve Analysis/ Gradation*:* The following test procedure is based on AASHTO T-27/ASTM 3515: first, materials of different aggregate sizes are sampled from the Bulbula-Alage design and build asphalt road project of the crusher plant and prepared; next, the sample is dried to 110^{o}c; subsequently, the sieves are set up in decreasing order of size; the process is then sieved mechanically; the materials retained on each sieve are weighed; and finally, the retained mass percentage and percent pass of each sieve are calculated respectively. The nominal sieve size is 19mm. Figure 3.2 below shows aggregate preparation and gradation.

$$Percent = \left(\frac{Weight\ Retained\ on\ each\ sieve}{Total\ Sample\ weight}\right) * 100 \text{ ………………Equation (3.1)}$$

Figure 3. 2 a) Aggregate preparation b) Aggregate gradation

Specific gravity: AASHTO T-85 & T-84 for coarse and fine aggregate test techniques are exercised, respectively, to determine the aggregate's specific gravity. The basic test procedures are as follows: first, prepare the sample (dry the aggregate at 105°C to 110°C for 24 hours and then let it cool again); then, weigh the dry aggregate using a calibrated balance (w_1); next to this, fully submerge the aggregate in water (w2); and finally, weigh the saturated surface dry aggregate as (w3). Figure 3.3 below shows specific gravity of fine and coarse aggregate.

And

Figure 3. 3 a) Course aggregate specific gravity b) Fine aggregate specific gravity

the last step to calculate for bulk the specific gravity (SG) is based on the equation below. But the formula below shows typically for coarse aggregate and for the fine is shown in the appendix.

$$SG= \frac{W1}{(W3-W2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (3.2)}$$

Water Absorption*:* The sequential processes to ascertain the aggregate's water absorption are as follows, based on AASHTO T-85 test methods: The first step is sample preparation, which includes cleaning the sample, drying it for 24 hours at 105°c to 110°c, and then cooling it again. Next, weigh the dry aggregate (W1), submerge it for 24 hours, lift it out of the water, and surface dry it. Finally, weigh the SSD of the aggregate (W2) and then calculate the water absorption as below;

$$\text{Water Absorption (\%)} = \frac{(W2-W1)}{W1} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (3.3)}$$

Aggregate crushing Value (Acv): The aggregate crushing value (ACV) is conducted using the corresponding techniques listed below, and the test methods follow the guidelines set forth in BS 812 part 110:1990. This is used to prepare the sample, which weighs about 2.6 kg, passes through a 14 mm sieve, and retains a 10 mm sieve. The sample is then oven-dried to 110 °C. After that, it is filled with the aggregate sample in three layers, each requiring 25 strokes of the tamping rod. Any excess aggregate is then trimmed out, and the cylinder containing the aggregate sample is placed in a compression machine, and a standard load of 400 KN is applied uniformly to the cylinder containing the aggregate sample for 10 minutes. The cylinder is then taken out of the compression machine and the aggregate is sieved through a 2.36 mm sieve; the retained mass on this sieve is then weighted as M2, and the fraction that passes through this sieve is weighted as M3. Figure 3.4 below shows ACV test.

Figure 3. 4 Aggregate crushing value reading

And the aggregate crushing value (A CV) is calculated by this formula below.

$$ACV= \left(\frac{Weight\ of\ finess\ passing\ through\ 2.36\ mm\ sieve}{Total\ sample\ weight}\right) * 100 \ \ldots\ldots\ \text{Equation (3.4)}$$

Flakiness Index Test*:* The asphalt aggregate's flakiness index is ascertained by applying the BS 812: section 105.1 test standard. According to this standard, the representative sample is first dried in an oven, and then it is sieved through standard sieves to separate the aggregate into size fractions. Each size of aggregate in the standard sieve is then tested for flakiness using a standard flakiness gauge, usually measuring between 63 and 6.3 mm. Finally, the total weight of the sample and flaky particles is recorded from each sieve fraction. Figure 3.5 below shows flakiness index test.

Figure 3.5 Flakiness index test

The flakiness index of the aggregate is calculated as follows.

Flakiness Index= $\left(\frac{Weight\ of\ flaky\ particles}{Total\ weight\ of\ the\ sample}\right)*100$ ………… Equation (3.5)

Soundness Test: The soundness test of the aggregate is a method used to evaluate the durability of aggregates (like sand, gravel or crushed sand) when exposed to weathering condition, particularly the effect of freeze-thaw cycles or the presence of salts. The goal is to determine whether the aggregate will degrade or break down when subject to this conditions over time. To know the soundness of the aggregate, AASHTO T-104-94 international standard test procedure is used. Based on this procedure firstly oven dried sample for course and fine aggregate, which passes through a specified sieves are taken, the sample is then weighted before immersed in Na_2So_4 solution as W_1, the weighted aggregate again completely immersed in the solution for 16 hrs. After 16 hrs the soaked aggregate is dried in the oven at 110°c for 18 hrs, the procedure immersion and drying of the aggregate is repeated for a total of 5 cycles. Finally the last dried cycle of aggregate is cooled at room temperature and the weight is recorded as w_2. Figure 3.6 below shows the aggregate immersing in the sodium sulphate solution.

Figure 3.6 Soundness test of aggregate

Soundness of the aggregate is calculated as below;

Soundness Loss = $\left(\frac{Initial\ weight - final\ weight}{Initial\ weight}\right) * 100$ .... Equation (3.6)

3.3.2 Bitumen tests

Bitumen is a petroleum residue black viscous thermoplastic material usually applied for road construction and waterproofing/insulating systems due to excellent adhesive and water barrier properties (Varanda et al., 2017). Bitumen is a black or dark-colored (solid, semi-solid, viscous), non-crystalline material that can be exist in different forms, such us rock asphalt, natural bitumen, tar and bitumen derived from oil, which is referred to as petroleum bitumen. Nowadays nearly all roads globally are paved with bitumen (Abiyot Mihret et al., 2018). Bitumen plays a bold role in road construction for its excellent adhesion and water proof properties. Bitumen of penetration grade 60/70 is sampled from Bulbula-Alage design and build asphalt road project asphalt plant storage. Testing of it is mandatory to check whether its properties meet the requirements. The basic tests of bitumen addressed in this research are the following with their procedures to keep their test validity.

Specific gravity of bitumen: The AASTHO T 228-96 test method is implemented to measure the bitumen's specific gravity. At the start of the test, the empty pycnometer is cleaned and its cap is weighed as W1. The bitumen, which was semi-solid, is then heated to 70 ^{o}c and the empty pycnometer is filled with the heated bitumen and weighed as W2. Ultimately, the pycnometer is cleaned from the bitumen once more and filled with distilled water at 23 ^{o}c and weighed as W3. Lastly, bitumen and water are added to the pycnometer, which is then weighed as W4. Figure 3.7 below shows specific gravity test of bitumen.

Figure 3. 7 Bitumen specific gravity test

The specific gravity of bitumen is calculated as follows below;

SG of bitumen = $\frac{W2-W1}{(W3-W1)-(W4-W2)}$ ………… Equation (3.7)

Ductility Test*:* To test the ductility of the bitumen, ASTM D 113 is used. Now the test is started by heating the bitumen sample to a temperature of 90^{o}c , then the heated bitumen is poured into the standard rectangular prismatic mold of dimension approximately 150mm*20mm*20mm) and cooled the sample at 25^{o}c for 30 minutes and again cool it in a water bath at 25^{o}c. After cooling it, the sample is placed on the ductility machine, which consists of two clamps that hold the ends of the sample and the clamps are gradually separated at a constant speed of 5cm/min as shown in figure 3.8 below, finally the point at which the elongated sample broken is taken as the ductility of the bitumen. The result is then recorded in centimeter.

Figure 3. 8 Bitumen in rectangular prismatic mold for ductility test

Penetration test of Bitumen*:* Penetration test of bitumen is a standard test used to measure the consistency and hardness of bitumen. This test helps to assess the quality of bitumen, which is commonly used in road construction and other operations. Regarding experimental procedures, AASHTO T 49 is applied to follow the right procedure while testing the penetration of bitumen. So firstly the bitumen is heated to appropriate temperature of 90^{o}c of its liquid state, then the heated bitumen is cooled again at 25^{o}c for 1.5 hours in to the two moisture cans, after this these two cooled bitumen filed cans also soaked in the water bath at 25^{o}c,now the standard penetration device of needle 1mm diameter and 50mm long is mounted on the string and calibrated, next to this the needle is allowed to penetrate on these two cans filled with bitumen sample under a standard weight of 100gram for 5 seconds at three different points of bitumen on each can, finally the average of individual bitumen specimen penetration in tenth of millimeter is taken as penetration value. Figure 3.9 below shows penetration test of bitumen.

Figure 3. 9 Penetration test for bitumen

Softening point: The softening point test is a standard method used to determine the temperature at which bitumen softens to a specified degree under controlled conditions. This test is important because it helps in assessing the temperature susceptibility of bitumen, which is crucial for its performance in different climatic conditions, especially in road constructions. During the execution of the softening point test for the bitumen, ASTM D 36 test method is considered. And hence the test is started first by heating the bitumen to 90°C.The molten bitumen is poured then into two brass ring molds and allowed the bitumen to cool at room temperature for 30 minutes, then the steel balls are attached on the top of each sample. Now the two prepared samples are placed into a ball-and-ring apparatus for 15 minutes at 5°C; after this, the sample is heated in the water bath at a steady rate of temperature of 5°C. Finally, a temperature reading is taken at 1-minute intervals of a 5°C temperature increase until the steel ball flow and dropped to a distance of 25mm .The softening point of the bitumen is then the average temperature of the temperatures at which the two balls are dropped. Figure 3.10 below shows the softening point test for bitumen.

Figure 3. 10 Softening point test of bitumen

3.3.3. Plastics (PET)

Many investigations showed that PET has better binding property than other plastics in road pavement and PET plastics are everywhere in today's lifestyle and are growing rapidly throughout particularly in a developing country like Ethiopia. They cannot biodegradable and pose a major problem to the society with regard to the management of these solid wastes. In addition to this some other studies narrates that PET plastic is chemically compatible with bitumen to use it as a partial binder in the hot mix asphalt.

Tough and clear, with exceptional strength and stiffness, chemical and heat resistant, attractive barrier properties for oxygen and carbon dioxide. It is utilized for packaging, soft drink and mineral water bottles, fibers for clothing, films, food containers, transport, building and appliance industry (as it is fire resistant) (Abiyot Mihret et al., 2018).To have appropriate plastic particles the plastic bottles (PET) and cups were cleaned then millided into small pieces then crushed and sieved in a way that it can passes through 3-5 mm sieve using shredding machine (H. Naghawi, 2018b) . The figure 3.11 below shows collecting, transporting, cleaning, shredding and processing of the PET plastic from Tatek, Rahel and guadegnochachew hibret sira Mahiber at Addis Ababa in Addisu Gebeya. Therefore this is simply characterization for plastic (PET).

Figure 3. 11 a) Shredding of the collected plastic b) Shredded plastic material

Table 3.1 Material test summary

Materials	Tests	Test methods	Specification criteria	Purpose
Aggregate	Gradation	AASHTO T-27	-------------	to check grading
	Specific gravity	AASHTO T/85	--------------	to know density
	Water absorption	AASHTO T/85	≤ 2%	to assess water absorption
	Crushing value	BS 812 part 110:1990	≤ 30%	to assess crushing value
	Flakiness index	BS 812: section 105.1	≤ 35%	to know flakiness index
	soundness	AASHTO T-104-94	≤ 15%	to know severity control
Bitumen	Specific gravity	AASHTO T-228-96	1.0-1.2	to check density
	Ductility	ASTM D-113	≥ 100cm	to know deformation
	penetration	AASHTO T-49	(60-70)mm	to know hardness
	softening	ASTM D-36	(46-56)o c	to know soften temperature

3.4. Conventional Marshall Mix Design (for reference mix)

Conventional hot mix asphalt mix design is conducted to use it as a reference mix even though it is not this research objective and the result is tabulated in table 3.3 below. As MS-2 Manual deals Conventional Marshall Mix design is a processes of determination of all Marshall Stability, flow and volumetric properties of the mix criteria's those can meet the requirements at a specified bitumen content by the conventional materials only. The conventional asphalt mix design here helped to determine the optimum bitumen content of it. The optimum bitumen content is then the bitumen content at which all the Marshall Mix design criteria can meet the specification set in the standard. The optimum plastic content in dry and wet processes is their respective percentage of the optimum bitumen content of the reference mix. To proceed the conventional Hot Mix Asphalt design, firstly, All raw materials those utilized in hot mix asphalt design, like aggregate (coarse and fine), filler and bitumen are characterized and the materials found those can meet the requirements set in the standards in either of ASTM, AASHTO, BS and ERA as discussed the above. After all the material tests passed, determination of aggregate blending proportions is proceed.

3.4.1. Blending of Aggregate

In Marshall Mix design of asphalt, after the material characterization the next step is aggregate blending proportions. Asphalt mix needs the combination of two or more aggregates, with varying gradations, to provide an aggregate blend that meets the gradation specifications for asphalt mix. Available aggregate materials, coarse aggregate, intermediate aggregate, fine aggregate and filler, were combined to get the well gradation within the allowable limits (TADEM, 2021). According to Asphalt institute manual series No.2 (MS-2) there are three methods of proportioning; Asphalt Institute's computer Assisted Asphalt mix Analysis (CAMA), Graphical and mathematical methods. In this mix design **mathematical method (Job Mix formula)** with suggested **trial and error** of aggregate blending proportion is applied to know the percentage of different size of aggregate.

Basic equations in mathematical method (Job mix formula) _ No matter for the number of aggregates combined or the method by which the proportions are determined, the basic equation expressing the combination is:

P = Aa+Bb+Cc+……………………………. Equation (3.8). Where, p = is percentage of the combined aggregates passing a given sieve A, B, C … = Percentage of material passing a given sieve for individual aggregates and a, b, c…= proportion of individual aggregates used in the combination. There total is =1.00

Accordingly the following available aggregates of coarse (25-12), intermediate (12-6), fine (6-0) and filler are combined to get the right gradation with in the allowable limits as per MS-2 Manual. The above mathematical method (Job Mix formula) helps to suggest different trial proportions of aggregate materials from the total gradation. The suggestion of percentage of each size of aggregate is calculated and compared to its lower and upper limits of specifications until the percentage of each size of aggregate fall within the limit. The suggested aggregate blending proportions were determined as 31.5%, 24%, 42.5% and 2% of nominal size of (25-12), (12-6), (6-0) and filler respectively. Summary of aggregate blending proportions are shown in table 3.2 and graphically in figure 3.12 below

Table 3. 2 Aggregate blending proportion

Kind of Aggregate		**Sieve size (mm)**							**Proportion of each sieve**
		25	**19**	**9.5**	**4.75**	**2.36**	**0.3**	**0.075**	
(25-12)mm		100	93.47	3.73	0.5	0.25	0.13	0.06	**31.5%**
(12-6)mm		100	100	90.59	4.56	0.6	0.24	0.14	**24%**
(6-0)mm		100	100	99.88	94.9	64.6	23.13	6.89	**42.5%**
Internal filler		100	100	100	100	100	99.8	92.8	**2%**
JMB		100	97.94	67.37	43.58	29.68	11.93	4.84	
Specification	**Upper limit**	100	100	80	65	49	19	8	
	Lower limit	100	90	56	35	23	5	2	

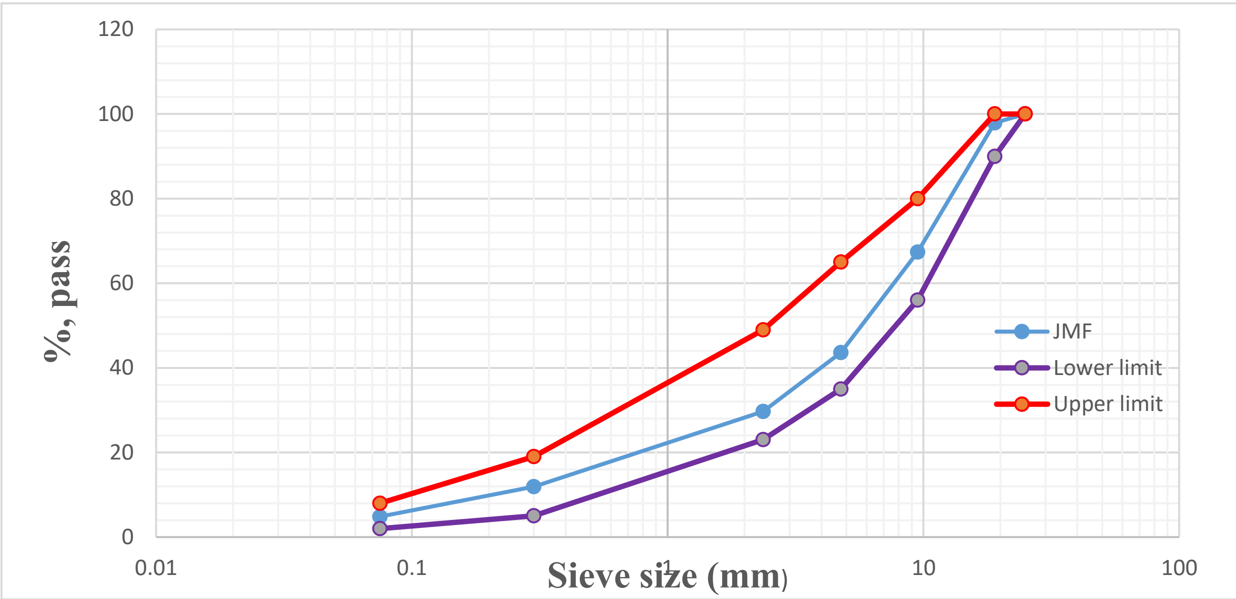

Figure 3. 12 Combined aggregate JMF

3.4.2. Volumetric properties of compacted paving mixtures

The guides set in asphalt institute manual series No.2 (MS-2 is applied to analyzed the volumetric properties of the compacted paving Mixes. These volumetric properties of the paving mix are Voids in air (AV), Voids in Mineral aggregate (VMA) and Voids filled by Asphalt (VFA).

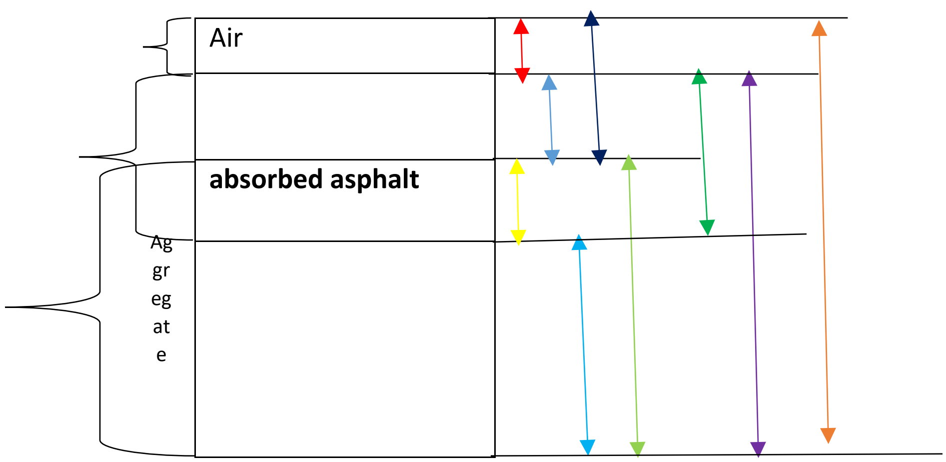

Figure 3.13 Representation of volumes in compacted asphalt mix

Where; Va= volume of air voids, Vfa= volume of voids filled with asphalt, Vba=volume of absorbed asphalt, **Vma** = volume of voids in mineral aggregate, **Vb** = volume of Asphalt, **Vsb** = volume of mineral Aggregate (bulk specific aggregate), **Vmm** = Voidless volume of paving mix, **Vse** = volume of mineral aggregate (effective specific gravity), **Vmb** = bulk volume of compacted mix.

Percent VMA In compacted paving Mixture*:* The voids in mineral Aggregate, VMA, defined as the intergranular void space between the aggregate particles in compacted paving mixtures that include effective asphalt content**.** The VMA is calculated on the basis of bulk specific gravity of the aggregate, compacted mix and aggregate content then expressed as a percentage of the bulk volume of the compacted paving mix.

$$\text{VMA} = 100 - \left(\frac{Gmb*Ps}{Gsb}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (3.9)}$$

Where; Gsb = bulk specific gravity of the total aggregate, Gmb = bulk specific gravity of the compacted mix, Ps = aggregate content, percent by total weight of mixture

Percent air voids in compacted mixture*:* The air voids, Va in the total compacted paving mixture consists of the small air spaces between coated aggregate particles. the volume percentage of air voids in a compacted mixture can be determined using;

$$\text{Va} = 100 * \frac{(Gmm-Gmb)}{Gmm} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (3.10)}$$

Where, Va = air voids in compacted mixture, percent of total mixture, Gmm = Maximum specific gravity of paving mixture, Gmb = bulk specific gravity of the paving mixture

Percent VFA in compacted mixture*:* The voids filled with asphalt, VFA, is intergranular void space between the aggregate particles (VMA) that are filled with asphalt. VFA, not including the absorbed asphalt is determining using;

$$\text{VFA} = 100* \frac{(VMA-Va)}{VMA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (3.11)}$$

Where, VFA = voids filled with asphalt, percent of VMA, VMA= voids in mineral aggregate, percent of bulk volume, Va = air voids in compacted mixture, percent of total volume

3.4.3. Optimum Bitumen Content Determination of the conventional Mix

Most of the time the standard aggregate weight to prepare a certain Marshall specimen is 1100 to 1400 grams. According to this conventional Hot Mix Asphalt design, 1100 gram weight of aggregate is taken. As MS-2 Manual presents, for surface coarse the air void ranges from (3-5) %. Based on this, 5% air void is assumed to determine optimum bitumen content. But at this air void percentage, all the Marshall criteria cannot meet the requirements as 4.8 % air void did. Due to this four bitumen contents (4.3%, 4.8%, 5.3%, and 5.8%) are considered in the mix design with their three trials. A total of 12 Marshall Specimens are prepared for Marshall Stability, flow and volumetric tests. Different property curves are prepared such as bitumen vs air void, bulk density, voids filled by mineral aggregate, voids filled by asphalt, stability and flow for the above different bitumen content. But for the time being, the property curves showed that all Marshall Mix design criteria are fulfilled at a 4.8% Air void limit. From the figure 3.14 below the corresponding optimum bitumen content for the mix was found to be 5 %.

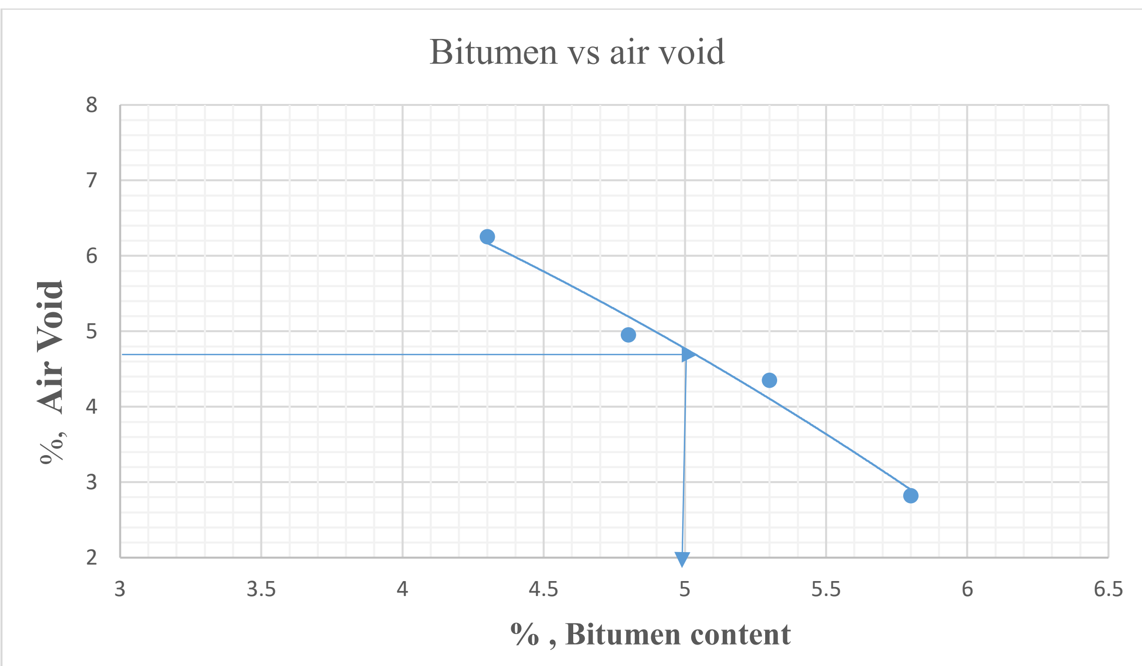

Figure 3. 14 Air void vs Asphalt content of conventional mix

Marshall Stability and flow test*:* It is a standard method used to evaluate the stability and flow characteristics of bituminous mixtures (asphalt concrete) used in road construction. The test is designed to determine the strength and deformation behavior of bituminous mixes under traffic loads. It provides valuable data to assess the quality of the asphalt mix and ensure its suitability for pavement applications.

According to ASTM D1559, the bituminous mixture is prepared by mixing a known quantity of bitumen with aggregate at the desired asphalt content, the mixture is heated and compacted in Marshall Mold typically using 75 blows on each side. After compaction, the specimen is allowed to cool to 25^{o}c and then immersed in a water bath at 60^{o}c for 30 minutes. Later on the soaked specimen placed on Marshall Stability machine which applies load at a steady rate. The load is then applied gradually on a Marshall specimen and the maximum load at which the specimen became failed is, stability of the mix. The flow is also measured by observing the amount of deformation in (mm) that the specimen undergoes at the point of maximum load. After the Marshall stability and flow is determined the bulk density of the mix, VA, VMA and VFA are analyzed by using equation 3.9, 3.10 and 3.11 respectively. Figure 3.15 below shows Marshall Specimen preparation for stability test.

Figure 3.15 Marshall Specimen preparation for stability and flow

After sample is prepared, Marshall Properties are analyzed. Figure 3.16 below shows the stability and flow test and the table 3.3 under it shows the summary of test results for conventional hot mix design.

Figure 3.16 Marshall Stability and flow test for conventional mix

Table 3. 3 Conventional hot mix asphalt criteria and respective result at 5 % OBC

SN	Marshal Criteria's	Mix Design Result	Heavy Traffic surface Specification	
			Min	Max
1	Number of blows for compaction	75	75	75
2	Stability	20.1	9	…..……
3	Flow	2.62	2	3.5
4	Air void, % (VA)	4.8	3	5
5	Voids in Mineral aggregate, % (VMA)	15.4	14	…………
6	Voids in filled by asphalt, % (VFA)	68.5	65	73
7	Bulk density of the mix, g/cm^3	2.238	....	………..

3.5. Marshall Properties of Plastic (PET) Modified HMA by dry process

The dry process involves adding shredded plastic to heated stone aggregate with a temperature of 180℃, and mixed with hot bitumen at a temperature of 160ºC (TADEM, 2021). The Marshall process of the plastic modified HMA in dry process is almost the same because in this process the materials used in the mix design are the same with that of the conventional one; the same different size of aggregate (25-12) mm, (12-6) mm, (6-0) mm and filler as well as the same penetration grade bitumen (60/70). The only difference is, in the dry process, plastic is added. During the course of the procedure, firstly PET and aggregates are mixed each other at high temperature before bitumen and later the coated aggregate with bitumen at a specified temperature usually at 160ºc. Then Marshall Stability and flow are tested as the conventional and the compacted mix volumetric properties and bulk specific gravity are evaluated. The plastic content at which all Marshall Properties fall under the specification is taken as optimum plastic content. In this study for dry process, suggestion of different plastic content by weight of OBC of conventional Hot Mix Asphalt is based on the existing studies. Figure 3.17 shows graphical representation of dry mix process.

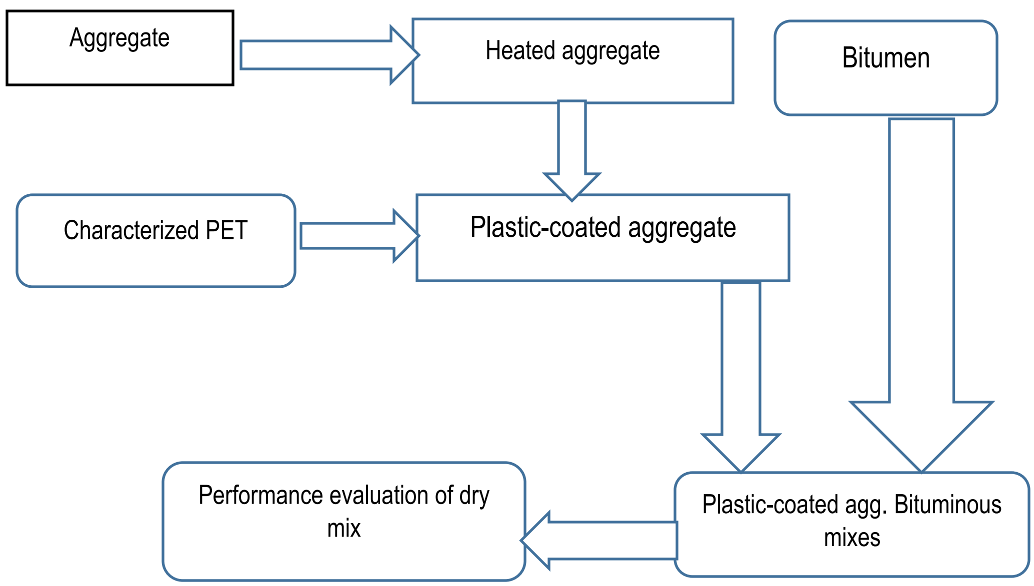

Figure 3. 17 Graphical representation of dry mix process

In the dry process the pre collected and washed waste plastic (PET) is shredded at (3.0-5.0) mm in a way that can enable melt easily and coated the aggregate to prepare the dry mix. Then the same conventional materials of aggregate (25-12) mm, (12-6) mm, (6-0) mm, internal filler and 60/70 penetration grade bitumen is used in this mix. Now the pre heated aggregate of temperature 180ºc is mixed with the shredded waste plastic at 180ºc thoroughly at vigorous speed to get the proper coat of the coarse aggregate and then filler is added before the bitumen. Finally the bitumen is added to complete the mix as shown below in fig 3.18.

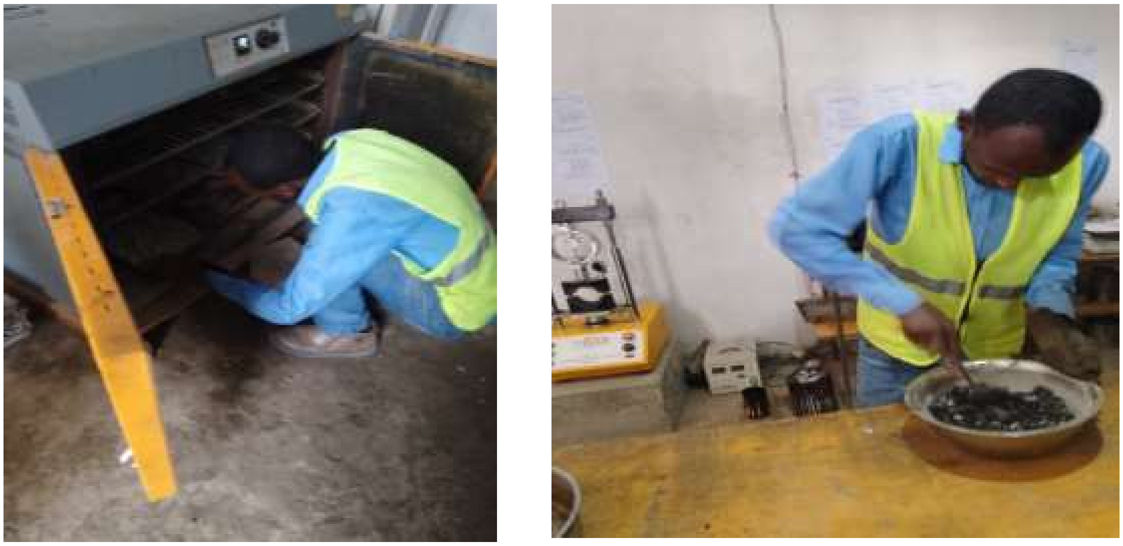

Figure 3. 18 Mixing of hot aggregate with molten plastic

The experimental design for the dry process is the same as to the conventional one. By using 5% OBC and 4.8% air void of conventional hot mix asphalt as a reference, replacement of different plastic content (5%, 10%, 15%, and 20%) by weight of 5% bitumen is established for dry mix. Then the stone aggregate, heated at 180^{o}c is mixed with these different percentage of plastic and next the bitumen is added to the plastic coated aggregate at 160^{o}c. 16 dry modified Marshall Specimens were prepared to investigate the effects on the Marshall properties (stability, flow, density and volumetric properties).

Optimum plastic content is now evaluated from the property curves of all Marshall Properties (stability, flow, density and volumetric properties) versus bitumen with different percentage of plastics and checked against the specification of Marshall Criteria.

3.6 Rut Resistance Performance of Plastic Modified Hot Mix Asphalt in Dry mix

Rutting commonly occurs along the wheel path. Rutting is also known as permanent deformation and can be termed as the accumulation of small amounts of unrecoverable strain due to applied loading to pavement (TADEM, 2021). Rutting has a visible negative impact on the performance of asphalt pavement, in particularly the ruts infiltrate water and causes hydroplaning. If the rutting is beyond the limit, a major structural failures are resulted. Hence, the rutting not only reduces the service life, but it may also affect the safety of highway users (Xu et al., 2011).

3.6.1 Rutting resistance test

Is a type of test used to evaluate the resistance of asphalt mixtures to permanent deformation or rutting under high temperatures and traffic loads. Rutting occurs when the asphalt surface deforms due to repeated wheel loads, causing grooves or ruts to form in the pavement. This can lead to poor ride quality.

Rutting test is conducted at Modjo-Hawassa Lot III high way project central laboratory. Based on AASHTO T 324-11, to evaluate the rut resistance of the dry modified HMA mixtures , the same different size of aggregate (25-12) mm,(12-6) mm, (6-0) mm, filler and 60/70 bitumen grade are used for wearing coarse. Having OBC 5%, 4.285% bitumen, 14.3% OPC (by weight of bitumen) and 1*12 kg aggregate is used to prepare one HMA Specimen at 160^{o}c.

Slab specimen compaction: As the above presented, in this study to evaluate the rut resistance performance, AASHTO T 324-11 is applied even though other studies mostly used BS test methods. Therefore after having the mix, 1*12 kg slab specimen of dimension 30cm*30*50mm is prepared for dry mix. Then the specimen is fixed with the slab compactor machine at a temperature of 150^{o}c, then 30kN was exerted on the specimen and compacted for 30cycles or 60 passes. After completing the compaction, the specimen is cooled at 25^{o}c for 24 hours and checked for air void. Based on AASHTO T 324-11 the air void should be (6.5-7.5) %. The air void is then 7.01 which is within the limit. The wheel tracking test is continued. Figure 3.19 below shows the slab compacting.

Figure 3. 19 a) Slab compactor Machine b) Slab compactor in motion

Wheel tracking test of Dry modified HMA Mixtures: After demolding the slab specimen, it is subjected to fix to the wheel track truck and left to one hour till the test temperature of the equipment reaches 60ºc. As immediately the temperature reaches 60ºc, the wheel track is set in motion for 10,000 cycles for around 6 hours (27.7cycl/min) with a known 700 N axle load to simulate the actual situation. At each 250 cycles, deformation reading is taken to determine the wheel tracking rate and wheel tracking depth (rut) of the specimen as per AASHTO 324-11. The detailed result is presented in the **Appendix D**. Figure 3.20 below shows reading at wheel tracking test

Figure 3. 20 Reading at wheel tracking test

Calculation and Expression of Wheel tracking rate and depth: As BS 598-110 wheel tracking rate is calculated by W_{TR} = 10.4*TRM (W/L) where w is the width of the tyre in millimeter, L is load applied in N and TR is the rate of increase of tracking depth. On the other hand wheel tracking depth is calculated as; R =r_n-r_0 where R is wheel tracking depth in millimeter, r_o is the initial value of the wheel tracking depth and r_n is the n^{th} reading in millimeter.

In this study AASHTO T 324-11 is applied to calculate wheel tracking rate and wheel tracking depth (rut). As AASHTO T 324-11 presents wheel tracking rate is the cycle of rate depth in the form of passes in (mm/pass) whereas tracking depth (rut) is taken the permanent deformation of the slab specimen at the end of 10,000 cycles in millimeter. The result shown in the **Appendix D** in detail. Figure 3.21 below shows slab specimen depth after wheel tracking rate test.

Figure 3. 21 Slab specimen after wheel tracking test

3.7 Moisture sensitivity of plastic modified hot mix asphalt in dry mix

Moisture damage is characterized as the missing of adhesion between aggregates and mortar, that causes stripping or loss of strength/modulus of mixtures and also results structural destructions under traffic loading. As the result, it is mandatory and meaningful to search approaches to solve the moisture damage of asphalt mixtures and asphalt pavements (Lin, et al 2012). A damage due to moisture is usually termed to as ‘’stripping’’. Stripping occurs when water or water vapor seeping into the asphalt film and the aggregates, thereby weaken the adhesive bond between the aggregate and the asphalt binder film. This can ’’separate’’ the asphalt from the aggregate. This process is based on a chemical phenomenon where water molecules reduces the bond between the asphalt and aggregate surface (TADEM, 2021). To test the moisture sensitivity of the asphalt, indirect tensile strength test is applied.

For this study indirect tensile strength test has been done at Modjo-Hawassa Lot III high way project central laboratory. The same different size of aggregate (25-12) mm, (12-6) mm, (6-0) mm, filler and 60/70 penetration grade bitumen is used for this test. Referring the OBC of the conventional hot mix asphalt as 5%, the partially replaced bitumen is 4.285% and 14.3% of OPC (by weight of the OBC). The experimental design for this test is as follows: based on AASHTO T-283; at the beginning to determine the air void as 7%, 4 trial specimens of each 3550 gram in 90 mm height and 150mm diameter mold is prepared to compact in the gyratory compaction. The number of gyrations for each specimen is set as 50, 60, 90 and 120. The air void is now fall on the 50 blows of gyratory compaction. Then the dry modified HMA mixtures is prepared as it is enough for 6*3550 grams of sample. Based on this, six specimen of each 3550 grams weight are prepared by the specified gyratory compaction of 50 gyrations to wet (conditioned) and dry (unconditioned) at 165°c. then this mix is kept at 60°c in the oven for 16 hours. After this it is again kept at 150°c for 2 hours to gyratory compaction and gyratory compaction is established as shown in figure 3.22 below.

Figure 3. 22 a) Gyratory compaction b) Compacted specimen

Three of the specimens for dry (unconditioned) are kept at 25°c for 24 hours and after this it is again at 25 °c in a water bath for 2 hours. Finally dry indirect tensile strength is tested.

Another three specimens for wet (conditioned) are kept also at 25°c for 24 hours. Then after, these specimens were kept at 60^0c for 24 hours in the water bath and kept again at 25°c for 2 hours. Finally wet indirect tensile strength is checked.

Indirect Tensile strength test (ITS): The moisture sensitivity test of asphalt, also known as the moisture susceptibility or water sensitivity test, is conducted to evaluate the ability of the asphalt mix to resist damage due to the presence of moisture. This is important because moisture can weaken the bond between the aggregate and the asphalt binder, leading to pavement distress such as striping, raveling and cracking.

According to AASHTO T 283 standards of test methods; indirect tensile strength test is performed for wet and dry condition specimen at a constant displacement rate. Before the test started the thickness of conditioned and unconditioned specimen is measured by caliper. Then the specimen is placed between two upper and lower bearing plates in the test machine and load is applied laterally to the specimen thickness then the ITS is calculated by considering the ring factor 123.36. Finally TSR is calculated by dividing the average of wet ITS to dry ITS. Figure 3.23 below shows indirect tensile strength test for dry process.

Figure 3. 23 Indirect tensile strength test

After recording the maximum compressive strength noted on the testing machine for each specimen the indirect tensile strength is calculated. $St = (2000 * 123.336 * p/\pi hD$) Where St = tensile strength, kpa, 123.336 is ring factor, P= maximum Load KN, h= Specimen thickness, mm D= Specimen diameter, mm Tensile strength ratio (TSR) = S2/S1, Where S1 = Average tensile strength of the dry specimen, kpa S2 = Average tensile strength of the conditioned specimen, kpa

3.8 Marshall Properties of plastic (PET) Modified HMA in wet mix process

In the context of plastic modified hot mix asphalt, Wet process refers to incorporating plastic materials typically in the form of waste plastics in to the asphalt mix during the production process. In this approach the plastic is added in a liquid or dissolved form often by melting or processing the plastic material, and then mixing them with the asphalt binder while it is in a heated. By mixing plastic with bitumen the ability of the bitumen to resist high temperature increases. The plastic waste is melted and mixed with bitumen in a predetemined ratio. Basically, mixing conducted when temperature reaches around 45.5°- 50ºC. But when plastic is blended, it remains stable even at 55°C. The vigorous tests at the laboratory level helped that the bituminous concrete mixes prepared using the modified bitumen fulfilled all the specified Marshall mix design criteria for surface coarse of road pavement (Abiyot Mihret et al, 2018). Marshall Stability, flow, bulk density and volumetric properties like (Va, VMA, and VFA) calculated and the procedures for this process is as the dry mix, the same material also used. The same different size of aggregate (25-12) mm, (12-6) mm, (6-0) mm, filler,60/70 penetration grade bitumen and shredded plastic (PET) of size (3-5) mm. wet process also used the OBC of the conventional HMA as a reference to determine its OPC. The figure 3.24 below shows the diagrammatic representation of wet process.

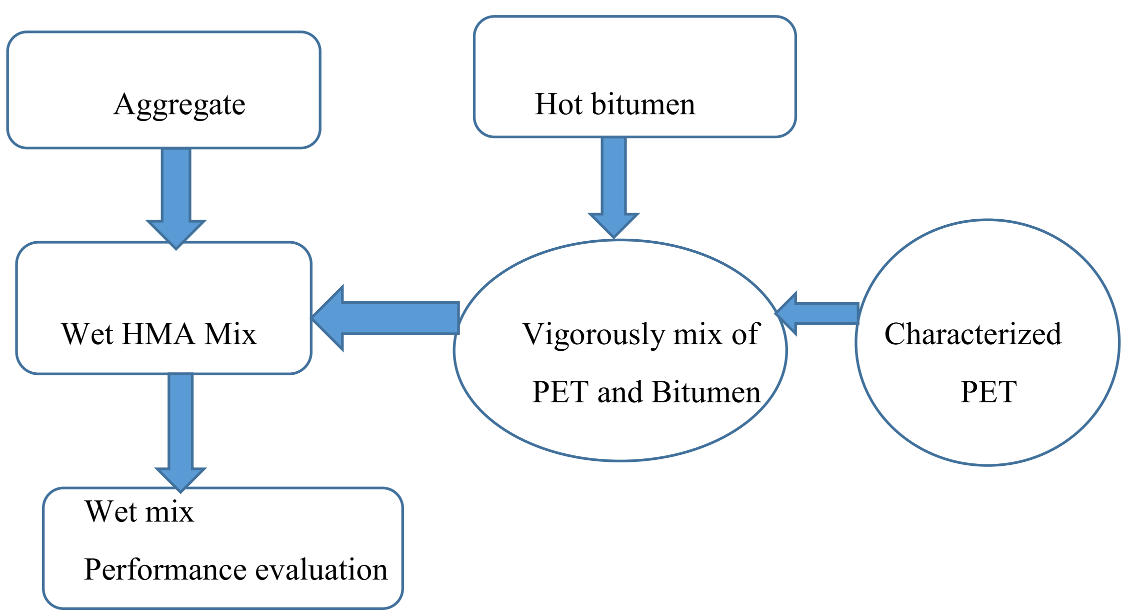

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Figure 3. 24 Diagrammatic representation of wet mix process

The Marshall test of the wet process is conducted at Bulbula-Alage design and build asphalt road project at Bulbula as the conventional and dry mix process. The Experimental design of Marshall Properties in the wet process is the same to that of dry process as stated above. But there are two basic difference from dry process, these are, in the wet process the plastic and the bitumen are mixed before the aggregate is added whereas in the dry process the aggregate and plastic are mixed before the bitumen is added. On the other hand during OPC determination, in the wet process, plastic content suggestion is based on the existing studies. (0, 2.5, 5, 7.5, 10, 12.5, and 15 wt% of asphalt binder) were proposed with wet process. The physical and mechanical properties of unmodified and DWP modified mixtures were examined using the Marshall Stability, indirect tensile strength, and wheel track tests (Nasr, 2016). Based on this, plastic contents of (2%, 4%, 6%, 8% and 10%) are suggested to determine the plastic content by weight of OBC of conventional mix that can fulfill all the Marshall Criteria. But for dry process the plastic content is suggested as earlier (5%, 10%, 15% and 20%) to fulfill all Marshall Criteria by weight of OBC of conventional mix. The figure 3.25 below shows mixing of bitumen with plastic before aggregate is added in the wet process.

Figure 3. 25 Mixing of bitumen with shredded plastic in wet process

3.8 Rutting resistance performance and moisture sensitivity evaluation of (PET) Modified HMA in wet mix

Starting from the materials used for the reference mix and the above performance of the dry mix, the procedure is also the same to that of the dry mix. The only difference here is wet mix. The materials like the same different size of aggregate (25-12) mm, (12-6) mm,(6-0) mm, filler, 60/70 bitumen grade and the same plastic of PET is also used. The two performance tests of wet process also conducted in Modjo-Hawssa Lot III high way project Central Laboratory.

3.8.1 Rutting resistance evaluation of PET Modified HMA in wet mix process

The mix is prepared by 2% (OPC), 4.9 % bitumen, the above mentioned aggregate and filler. In the wet process, the same weight as dry process of 1*12 kg slab specimen is prepared first to determine the air void by 30 cycles of compaction with standard load 30 KN. the air void is now found at 6. 7% and it is within the limit. Then the rut and wheel track rate also calculated as dry process by using AASHTO T 324-11.

3.8.2 Moisture sensitivity performance evaluation of PET Modified HMA in wet mix process

To evaluate the moisture sensitivity of the wet mix, a mix is prepared also by 2 % plastic, 4.9 % bitumen, the mentioned aggregate above and filler. To determine the air void, 4 trials of specimens each weigh 3550 gram is compacted in the same cylindrical mold as dry process by gyratory compaction. Different number of gyration is applied to these four specimens, as 40, 60, 80 and 110. The required air void of 7 % is the found at 110 gyration. Based this specified number of gyration 6 specimens, three for dry (unconditioned) and another three for wet (conditioned) are prepared. Finally ITS determination of (conditioned and unconditioned) and TSR analyzed is as dry process based on AASHTO T 283.

3.9 Optimization of dry and wet processes performance

Two alternatives of dry and wet processes are optimized by using different criteria’s. These criteria’s are rutting resistance (wheel tracking depth and wheel tracking rate), moisture sensitivity as (TSR), stability, VMA and bulk specific gravity from Marshall Properties of the two mixes. Because stability, VMA and bulk specific gravity have a direct relationship with rut resistance and moisture sensitivity resistance performance. So to select one type of waste plastic modification of hot mix asphalt with these criteria, optimization is reminded. The methods to optimize these processes, multi-criteria decision Analysis particularly TOPSIS (Technique for order of preference by similarity to ideal solution) is implemented. This method refers its concept on the Euclidean distances of the alternatives from maximization and ideal costs. It is a technique that rises the benefit criteria/ attributes and declines the cost criteria/attributes. The best alternative will be the one which has the shortest distance from the ideal beneficial solution or one and the farthest distance from the ideal cost solution (Slebi-Acevedo, 2019). After identified the alternatives (i) and criteria's (j), a Decision matrix is now constructed as (X_{ij}) from the table 3.4 below.

Table 3. 4 Alternatives and their criteria value

Alternative	**Criteria**					
	Stability (kN)	Bulk specific gravity	VMA	Wheel tracking Depth (mm)	Wheel tracking rate (mm/pass)	TSR (%)
Dry process	21.26	2.207	16.69	1.31	0.000065	90.2
Wet process	16.01	2.199	17.01	2.39	0.00012	84

The decision matrix is also normalized again as (R_{ij}).

$$R_{ij} = \frac{Xij}{\sqrt{\sum_{j=1}^{m} Xij^2}} \text{ .... Equation (3.12)}$$

Where; X_{ij} is the original value for alternative i and criteria j. then weight is assumed for (stability, bulk specific gravity, VMA, wheel tracking depth, wheel tracking rate and TSR) criteria as (w_1=0.2, w_2= 0.1, w_3=0.1 and w_4=0.2,W_5=0.2, W_6=0.2) respectively based on their importance. After each criteria is weighted, weighted normalized decision matrix is computed as;

$$Vij = w_j * R_{ij} \text{ ....Equation (3.13)}$$

Now again ideal solution (A^+), best value for each criteria for benefit and negative ideal solution (A^-) worst value of criteria for benefit in each column is determined. Next to this, ideal Euclidean distance (D^+) and negative Euclidean distance (D^-) are computed by using ideal, negative ideal solution and weighted normalized decision matrix as follows,

$$D^+ = \sqrt{\sum_{j=1}^{m} (Vij - Aj\text{^}+)^2} \text{ .... Equation (3.14)} \quad \text{and}$$

$D^- = \sqrt{\sum_{j=1}^{m}(Vij - Aj\hat{}-)^2}$ …………………...Equation (3.15)

Where, D^+ and D^- are the distance of alternative *i* from the ideal solution and the distance from the negative ideal solution. Finally similarity index (closeness coefficients), C_i for each alternative are computed to rank the alternatives and C*i*;

$C_i = \frac{Di-}{Di^+ + Di-}$………………Equation (3.16)

The results are discussed later in **Appendix F** in detail to show clearly the procedures and results.

3.10 Cost comparison of dry and wet processes

Cost is a critical issue especially for the developing country. Ethiopia is one of the developing country in Africa. So introducing of cost effective and performance improved pavement road construction practice is the wish of the country. On the course of improving the performance of conventional asphalt paving mix, cost should come next to safety. Due to this, implementing cost analysis between wet and dry processes is essential to have cost effective road construction practices. The Cost of Waste Plastics: Rs.7 / Kg. The Cost of Processing: Rs.5 / Kg. The Total cost of Waste Plastics: Rs.12 / Kg. as per the test results, Optimum percentage of plastic is around 8% by Wt. of bitumen. Generally roads in India are constructed in basic width of 3.0 m, 3.75 m. and 4.0 m. Consider 1 Km length road of width 3.75 m. it uses bitumen approx. 21300 Kg (Akshar Patel, 2018).

In this study 1 km length by 7m width with 5 cm thickness of the surface road section is taken to compare the cost reduction between in wet and dry processes from that of reference mix. Firstly 1km*7m*5cm volume of conventional HMA cost is calculated in terms of bitumen (OBC) only. Then after, 2% of shredded waste plastic (PET) is taken as a partial replacement of bitumen by weight of OBC in the wet process and 14.3% of PET by weight of OBC is taken in the dry process. After the conventional HMA is modified in dry and wet processes, the respective cost of both processes in terms of bitumen and Optimum plastic content is calculated. Now again the binder (bitumen and optimum plastic content) costs for wet and dry processes are subtracted from the conventional hot mix asphalt bitumen cost. Finally the cost reduction is computed in wet and dry processes relative to the reference mix. Figure 3.26 below shows the assumed road section to calculate the conventional hot mix asphalt, dry and wet modified hot mix asphalt binder cost to compare cost reduction of dry and wet processes.

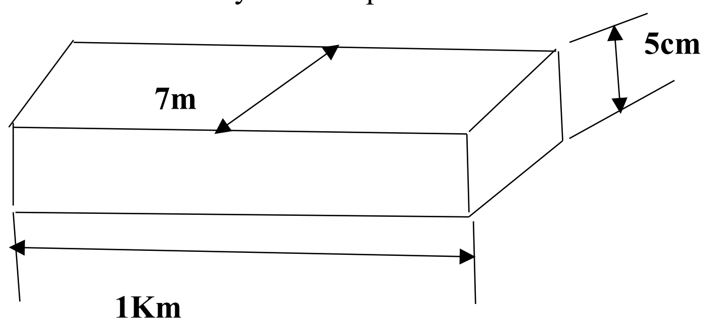


Figure 3. 26 Assumed Asphalt road section

Cost comparison result is presented in the **Appendix G** below clearly.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1. Introduction

This study first characterize the materials those used for hot mix asphalt. These materials covers like aggregate, bitumen and plastic (PET). The context of characterization of materials means conducting the basic quality test for aggregate and bitumen. But the PET plastic is already shredded to a required size of (3-5) mm as discussed and shown in chapter three fig 3.11.Therefore further characterization for this material is not needed in this section.

As early stated, conventional hot mix asphalt mix design is conducted in chapter three as a procedure to establish dry and wet processes mix design. Like conventional hot mix design, 3 trials for Marshall and 1 specimens for Maximum theoretical density to each plastic content of dry and wet processes are taken. After all, as discussed above, the optimum bitumen for Conventional hot mix design is found to be 5% at air void of 4.8% which fulfill the Marshall criteria set for the surface coarse as presented in chapter three. Therefore conventional hot mix asphalt cannot discuss in this section. Based on this 5% optimum bitumen content (OBC), partial replacement of bitumen by plastic (PET) for dry and wet processes are discussed in detail.

Dry and wet processes Plastic (PET) modified hot mix asphalt mix design is conducted to get their respective optimum plastic content to evaluate their Marshall stability, flow and volumetric properties of the modified mix as well as their performances. For dry process 5%, 10%, 15% and 20% of bitumen's and for wet process 2%, 4%, 6%, 8% and 10%of bitumen's content taken for trials. Totally again 16 specimens for dry and 20 specimens for wet processes are prepared for Marshall and maximum theoretical density analysis.

Optimization of the two processes is established based on the stability, VMA, bulk specific gravity, rutting resistance (wheel tracking depth and wheel tracking rate) and moisture sensitivity (TSR) to select the feasible and more optimal processes in the road construction practices. Finally the simple cost analysis between the two processes is implemented.

4.2 Material characterization

In this section the test findings of Hot Mix Asphalt ingredient materials are presented in either of graphically or tabular form. Basically the test results of aggregate and bitumen are explained.

4.2.1 Aggregate

Aggregate is the bearing and most abundant material in the asphalt concrete. Almost 95% of the asphalt mix is aggregate. In this study, Basic aggregate tests are conducted. These are gradation, Specific gravity, water absorption, flakiness, aggregate crushing value and soundness by sodium sulphate.

Gradation (Sieve Analysis): The test is conducted to determine whether the aggregate is well graded.

Table 4. 1 combined aggregate gradation

Sieve size (mm)	Weight retain in (gram)	% Retain	% Pass	Specification	
				Lower	Upper
25	0	0	100	100	100
19	1283.4	1.8	98.2	90	100
9.5	908.8	30	68.2	56	80
4.75	609	21.25	46.95	35	65
2.36	876.8	14.23	32.72	23	49
0.3	325	20.49	12.3	5	19
0.075	198	7.59	4.64	2	8
Pan	-	-	-	-	-
Total	**4278**				

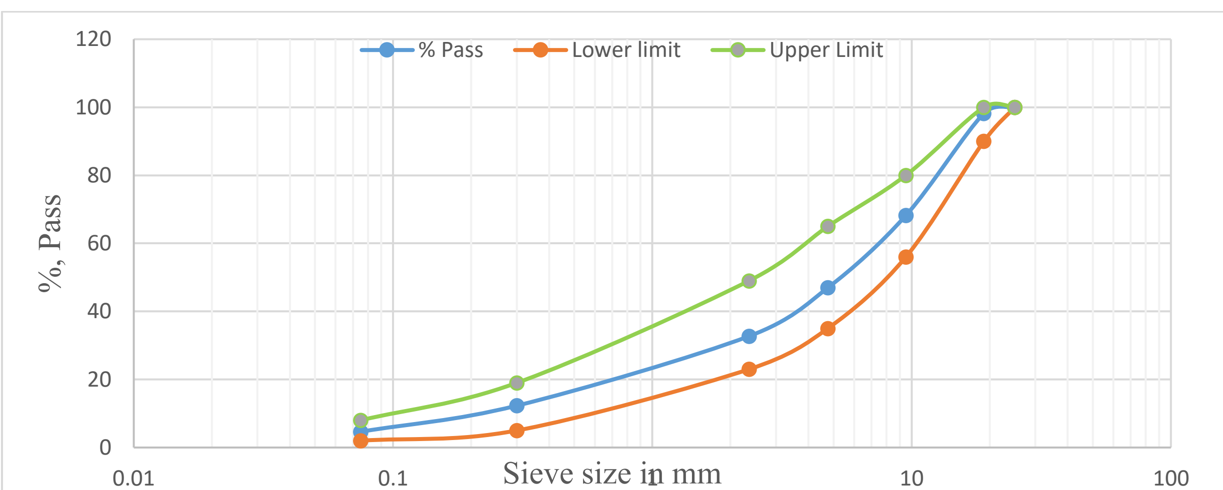


Figure 4. 1 Combined aggregate gradation

As shown the above from the table 4.1 and its graph, percent retained on each sieve is calculated by using equation 3.1. And the percent of pass on each sieve is found with in the ERA 2013 standard technical specifications. Therefore the particle size distribution of the aggregate is well or dense for the asphalt aggregate to use.

Specific gravity and Water Absorption*:* As stated above in chapter three the specific gravity of the aggregate is a measure of its strength. Due to this specific gravity test is established for both coarse and fine aggregate. On the other hand Water absorption is the ability of aggregate to absorb or retain water. Table 4.2 below shows specific gravity and water absorption.

Table 4. 2 Combined aggregate's specific gravity and water absorption

Description	Results found	Specification
Apparent specific gravity (Gsa)	2.577	-
Bulk specific gravity,SSD (Gsb)	2.517	
Water Absorption	1.58	≤ 2 %

As shown above from the table 4.2, bulk specific gravity and Water absorption of each aggregate is calculated by using equation 3.2 and 3.3 from chapter three respectively and the combined aggregate's bulk specific gravity and water absorption is done by combined each aggregate by their respective mix proportion. Based on the principle that, apparent specific gravity of the aggregate is greater than bulk specific gravity and the table above also proved it. As the AASHTO T-85 or BS 812 part (1975) standards, the water absorption is also under 2%.

Aggregate crushing Value (ACV)*:* As declared above the test is established to determine the crushing value of the aggregate that is applicable for the hot mix asphalt mix design. Two masses of 2638 and 2670 grams are taken for two trials. By using a standard size of sieve 14&10 mm, mass is recorded as M1 after sieving that pass on 14 mm and retain on 10 mm. 400 KN is applied for 10 minutes at a steady rate for both trials. After test, a mass retained on 2.36 sieve is then recorded as M2 and that pass on 2.36 mm sieve as M3. Then ACV of the aggregate is 16.45 % which is the average of the two trials and again checked against the standards and found acceptable as shown in the table 4.3 below.

Table 4. 3 Aggregate crushing value

Description	**Trials**	
	1	2
Standard sieve size in (mm)	10-14	10-14
Duration of testing in (minute)	10	10
Standard applied load in (kN)	400	400
Mass of aggregate before test, passing through in 14mm and retain in10mm ,M1 (gm)	2638	2670
Mass of aggregate after test ,retained in 2.36mm, M2 (gm)	2208	2228
Mass of aggregate after test, pass in 2.36mm,M3 =[M1-M2] in (gm)	430	442
ACV(%) =(M1-M2)/M1*100	16.3	16.6
Average (ACV)%	**16.45**	
Specification	$\leq$ **30** %	

As shown above from the table 4.3 the Aggregate crushing value is calculated by using equation 3.4 and found 16.45%. According to BS 812 Part 110:1990 standards it is under the maximum limit of 30%.

Flakiness index*:* In this study the aggregate also characterized base on its shape in terms of flakiness**.** Because the more flaky aggregate is not suitable for the hot mix asphalt. Especially the stability of the mix became weak. If the stability of the mix cannot achieve the required stability, it fails before the period of service. Totally 2355 and 2191 grams of sample weight is taken for two trials to check the aggregate flakiness. A standard sieve size of (63-10) mm and a standard slot gauges of (63-6.3) mm are used to check the flakiness of the sampled aggregate. The passing mass from the 2355 and 2191 grams in standard slot gauge is 317 and 290 respectively as in table 4.4 below shown.

Table 4. 4 Flakiness index test result

Trial 1				Trial 2	
Sieve size in mm	***Slot thickness gauge (mm)***	***Weight retained on sieve (gm)***	***Weight pass in gauge (gm)***	***Weight retained on sieve (gm)***	***Weight pass in gauge (gm)***
63	63-50	0	0	0	0
50	50-37.5	0	0	0	0
37.5	37.5-28	0	0	0	0
28	28-20	413	71	432	73
20	20-14	930	92	820	112
14	14-10	603	90	588	68
10	10-6.3	407	64	351	37
Total		2355	317	2191	290
Flakiness index, %		**13.5**		**13.2**	
Average		**13.3**			
Specification		$\leq \mathbf{35}\%$			

As observed from the table 4.4 above, the flakiness index is calculated by using equation 3.5. Based on BS 812, Part 105.1(1990) the maximum flakiness index is 35% and the average flakiness of the two trials is found 13.3 % which is under the maximum limit and acceptable.

Soundness test*:* To check the durability of the aggregate against to freeze and thaw soundness test is established. Na_2so_4 solution of specific gravity 1.159 gm/cc is used to check a mass loss from the aggregate (Coarse and fine) by exposing the aggregate for 5 cycles and each cycle of approximately 18 hours duration is used to immerse in to the solution and the result is found as shown in table 4.5 below.

Table 4. 5 Soundness test result for fine and coarse aggregate

Sieve size (mm)	Sieve size used (mm)	Weight (gm)	% Rt of grading sample (x)	Mass of test fraction (gm)		% passing after sieve (v=y-z/y*100)	% wt. loss= (w=v*x/100)
				Before test (y)	After test(z)		
63mm-50mm	31.5	3000±300					
50mm-37.5mm	31.5	2000 ± 200					
37.5mm-25mm	16	1000 ± 50					
25mm-19mm	16	500 ± 50	1.15	550	502	8.7	0.1
19mm-12.5mm	8	670 ± 10	27.64	680	610	10.3	2.8
12.5mm-9.5mm	8	330 ±15	16.67	345	327	5.2	0.9
9.5mm-4.75mm	4	300 ± 5	21.41	305	287	5.9	1.3
Total Loss on sodium sulphate (SSS) % Course Aggregate							**5.08**
4.75mm-2.36mm		100	13.80	100	90	10.0	1.38
2.36mm-1.18mm		100	8.51	100	89	11.0	0.94
1.18mm-0.600mm		100	4.70	100	91	9.0	0.42
0.600mm-0.300mm		100	3.00	100	90	10.0	0.30
Total Loss on sodium sulphate (SSS) % Fine Aggregate							**3.04**

As observed from table 4.4 above, after the aggregates are exposed to the Na_2So_4 solution for 5 cycles up to 18 hours for each cycle, the mass loss from coarse and fine aggregate is found 5.08 % and 3.04 % respectively. Percent passing or initial mass loss is calculated based on equation 3.6 and the corrected weight loss is the product of % retained of the grading sample and % passing after sieving. According to AASHTO T-104-94 the maximum limit for the coarse and fine aggregate is 10 % and 16 % respectively in Na_2So_4 solution. Therefore it is shown that the results of the fine and coarse aggregates are under the limit set.

4.2.2 Bitumen quality test results

In this study only four basic bitumen quality tests are conducted. These are specific gravity, penetration, softening point and ductility. Therefore this section discusses about the test results of the bitumen to characterize it as an excellent binder material for hot mix asphalt design.

Specific gravity: The test is established to assess the density and the behavior of bitumen at different condition .To determine the specific gravity of bitumen three trials are taken. As early stated, grade of bitumen is 60/70. The table 4.6 below shows the results of different trials for specific gravity of bitumen.

Table 4. 6 Bitumen specific gravity test result

Description	**Trial 1**	**Trial2**	**Trial3**
W1. Mass of pycnometer (gm)	70.70	70.70	70.00
W2. Mass of pycnometer+Bitumen (gm)	122.60	120.80	112.60
W3. Mass of pycnometer + Water (gm)	179.80	179.70	178.40
W4. Mass of pycnometer+ bitumen +Water (gm)	181.20	180.60	179.50
Specific gravity of bitumen $= \frac{W2-W1}{(W3-W1)-(W4-W2)}$	1.03	1.02	1.03
Average specific gravity of bitumen	**1.024**		

As shown above from table 4.6 the specific gravity of bitumen is found 1.024. The specific gravity is calculated by using equation 3.7. As stated in chapter three usually the specific gravity is between 1.0 and 1.2 and the result is found within the limit.

Ductility*:* Ductility is one of the basic quality test for the bitumen which permits a great deformation or elongation for the bitumen. The more elongate the bitumen it can be then the more flexible which can prevent the hot mix asphalt from being brittle. In this study ductility test is established to characterize it before use for hot mix asphalt .Therefore; two specimens A and B are taken to conduct the ductility test of the 60/70 penetration grade bitumen. Different results are recorded as 130 cm for A and 120 cm for B as shown in table 4.7 below.

Table 4. 7 Bitumen ductility test result

Ductility (cm)		Average	specification
A	130	125	≥ 100
B	120		

As shown from the table 4.7 above the ductility is the average of the specimens of A and B which is 125 cm.so the ductility of the bitumen is now found (100^+cm) and this in turn can full fill the requirement's set above.

Penetration of Bitumen: In this study another basic test that helps to characterize the bitumen was penetration value. Penetration is the measure of consistency and hardness of the bitumen while using the bitumen in the road construction practices. It is totally one measure of quality for bitumen to characterize it. The low the penetration value implies the hard bitumen and is applicable in the hot area where as the high penetration value of the bitumen indicates the soft one and is usually applicable in the cold area. Table 4.8 shows the penetration value of bitumen.

Table 4. 8 Penetration test result of bitumen

Specimen	Penetration value (10^{th} of mm)			Average	Specification (AASHTO T-49)
	Reading 1	Reading 2	Reading 3		
A	63.1	61.4	63.9	**62.8**	**60-70**
B	65.9	66.3	65.5	**65.9**	**60-70**

As shown from the table 4.8 above two specimens A and B are proposed. Three readings for each of A and B are taken to determine penetration value in 10^{th} of millimeter for the specimens. Finally the penetration value for A and B is found 62.8 and 65.9 respectively. And these values are within the specification limit set in AASHTO T-49.

Softening point: A temperature at which bitumen can softens under a specified controlled condition is called softening point of bitumen. It indicates how much the bitumen is sensitive to a temperature. Table 4.9 shows the findings of 60/70 penetration grade bitumen softening point during the course of laboratory test.

Table 4. 9 Softening point test result of bitumen

<table>
<tr><th colspan="2">Softening point</th><th>Average</th><th colspan="2">Specification</th></tr>
<tr><th>Ball A</th><th>Ball B</th><td rowspan="2">50.1^{o}c</td><th>Lower</th><th>Upper</th></tr>
<tr><td>50^{o}c</td><td>50.2^{o}c</td><td>46</td><td>56</td></tr>
</table>

As shown from table 4.9 the softening point of the bitumen is the average temperature of the two balls fall down the required depth of 25 mm. According to ASTM D 36 the softening point is so found within the specification limit and acceptable for hot mix asphalt application.

4.3 Evaluation of Marshall Properties of plastic (PET) Modified HMA in the Dry process

In this study the effect of plastic (PET) on Marshall Properties like stability, flow, bulk specific gravity and volumetric properties (voids filled by mineral aggregate, voids filled by air and voids filled by asphalt) are evaluated in the dry modified hot mix asphalt.

4.3.1 Plastic (PET) effects on the stability of dry modified HMA

The stability is the ultimate load that the dry modified hot mix asphalt bears from the traffic. This stability therefore affected by the plastic content added in the aggregate which replaces the bitumen. The test is established at 60^{o}c. The plastic content is added by weight of OBC as 5%, 10%, 15% and 20% but the optimum plastic content is found at 14.3%. At 14.3 % most of the Marshall criteria can meet the requirements except air void and this air void attain the requirement after addition of 45 blows compaction for each top and bottom face of the specimens from the conventional compaction (75 blows). Figure 4.2 below shows the effect of different plastic content on the stability of the mix. The minimum stability for heavy traffic surface course is 9 KN as stated in ERA 2013 standard technical specifications.

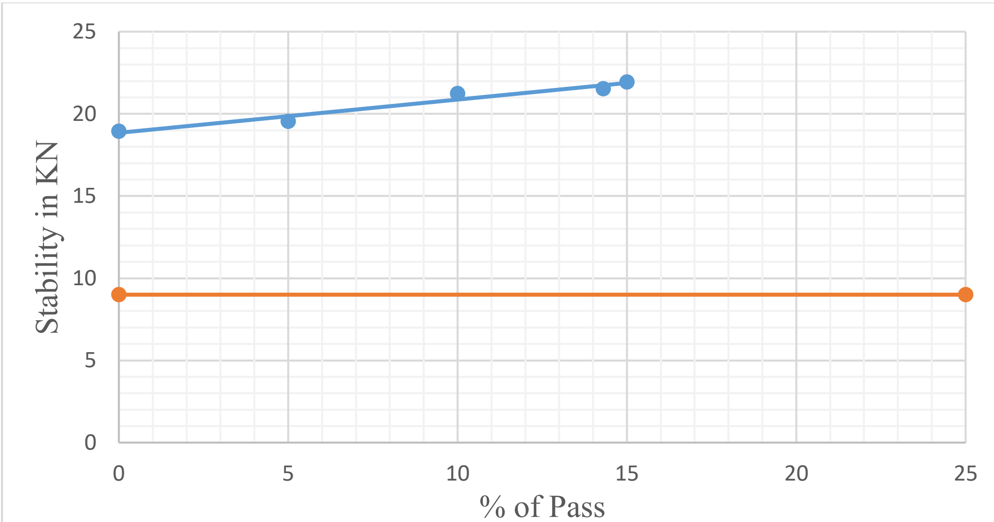


Figure 4. 2 Effect of plastic content on stability in dry mix process

As shown from the figure 4.2 above the stability beginning increase at 5 % ,10%, 14.3% and 20 % of plastic content. Even though as stability increases with plastic content increase, below and above 14.3% plastic addition cannot fulfill the requirement other Marshall criteria. Therefore the optimum plastic content is found at 14.3%.

4.3.2 Plastic (PET) effects on the flow of dry modified HMA

The Marshall flow is a measure of vertical deformation of the hot mix asphalt at a time of stability test at 60°c. Most of the time as the stability becomes increases the Marshall Flow value decreases. According to ERA 2013 Standard technical specifications for heavy traffic surface course the flow value should be between (2-3.5) mm. Figure 4.3 below shows the effects of different plastic content on the flow value for dry modified mix. As observed from figure the flow value decreases as the plastic content increases forward. If the flow value is under 2 mm the mix become stiff and can be brittle instead of flexible where as if the flow value is above 3.5 mm it is exposed to rutting distress of the flexible pavement. But at the optimum plastic content of 14.3% the flow value is within the limit and gets safe. Not only optimum plastic content but also all other plastic contents suggested for the dry modified mix, their flow value shows with in the range. Even though the flow value is within the limit other criteria’s fail to meet the requirement and only the flow value (2.35mm) at 14.3% plastic content is taken as the flow value of the mix.

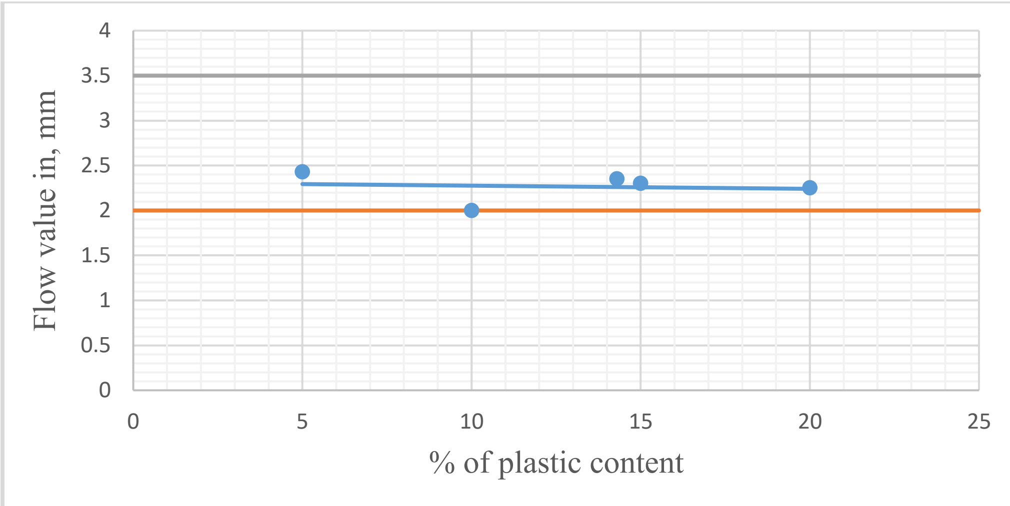


Figure 4. 3 Effect of plastic content on the flow value in dry mix process

4.3.3 Plastic (PET) effects on the bulk specific gravity of dry modified HMA

Bulk specific gravity of the hot mix asphalt refers to the durability, workability and resistance to deformation of the wearing course. Addition of plastic (PET) to coat the coarse size aggregate affects the bulk specific gravity of the mix. As the plastic content increases the specific gravity of the mix decreases. Figure 4.4 below shows the bulk specific gravity of the mix at different plastic content.

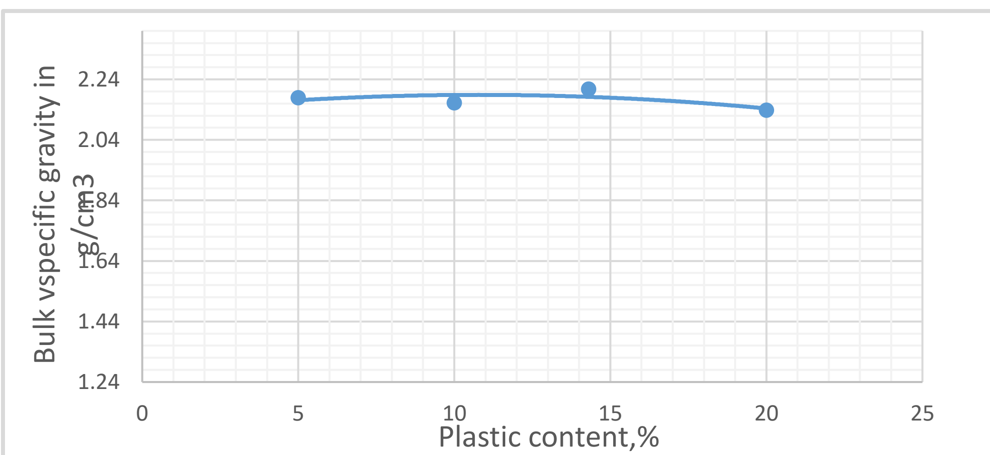


Figure 4. 4 Effect of plastic on specific gravity in dry mix process

As shown from figure 4.4 above as the plastic content increases the bulk specific gravity decreases except for optimum plastic content. It is the reason that the coated aggregate denied from getting asphalt and loses its weight and results in reduction of bulk specific gravity. At 14.3 % plastic content, the bulk specific gravity increases due to more compaction to attain the required air void.

4.3.4 Plastic (PET) effects on Voids filled by mineral aggregate of dry modified HMA

As MS- 2 manual says VMA is the intergranular void space between the aggregate particles in compacted paving mixtures that include effective asphalt content. The minimum value of VMA for heavy traffic surface course is 14 %. Figure 4.5 below shows effect of plastic on VMA.

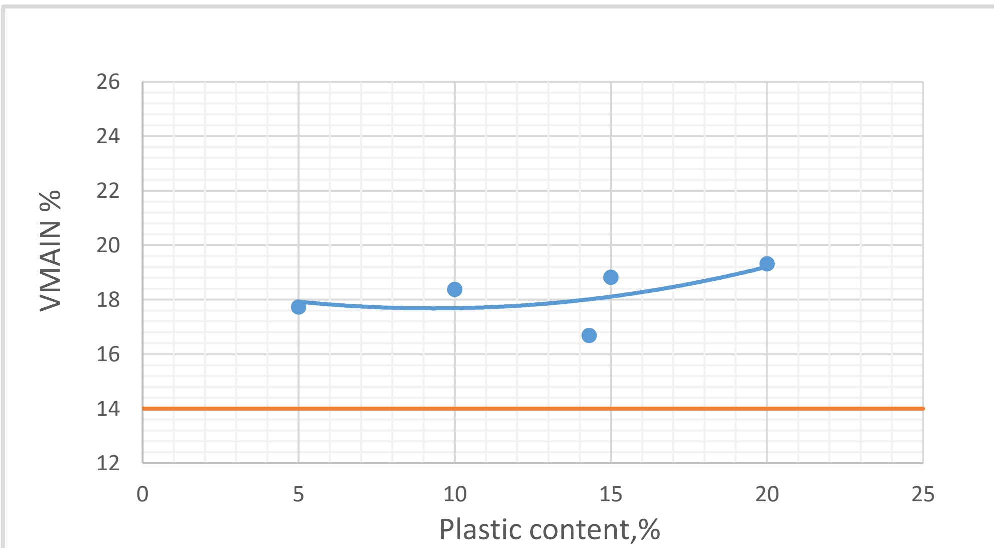


Figure 4. 5 Effect of plastic on VMA in dry mix process

According to figure 4.5 above as the plastic content increases forward, the value of VMA also increases up to10% and again decreases up to14.3 % Plastic content and again increases. All the suggested plastic content for dry mix full fill the VMA value but except 14.3 % plastic content others cannot fulfill other Marshall criteria. VMA is calculated by using equation (3.9) and the VMA value at 14.3 % is taken as 16.69 % which is above 14 %.

4.3.5 Plastic (PET) effects on Voids filled by air of dry modified HMA

The air spaces that exist in the total compacted paving mixture is called air void. Marshall design criteria recommends air void of heavy traffic surface coarse to be 3 to 5 percent.

Figure 4.6 below shows the effect of plastic content on the air voids in the dry mix.

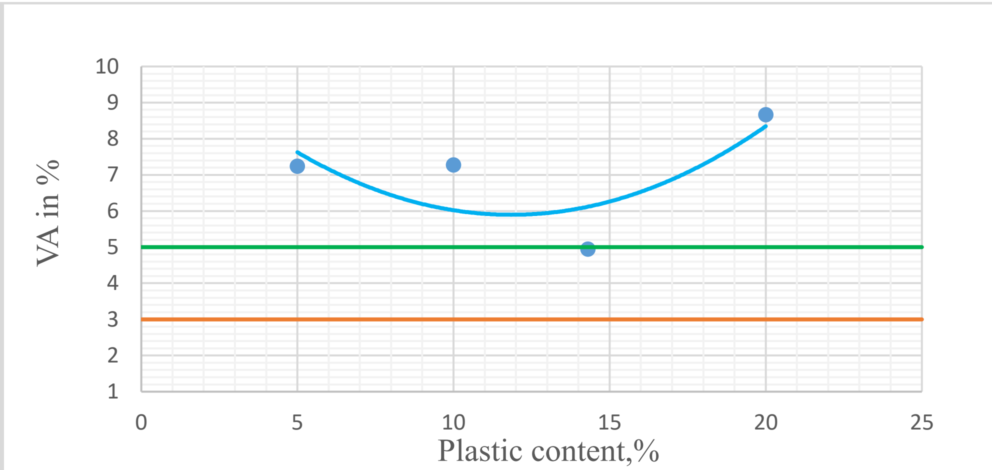


Figure 4. 6 Effect of plastic on VA in dry mix process

Based on figure 4.6 above the the air void of the compacted paving mix is increased from 5 % up to 10 % and gets again decreases up to 14.3 % and again starts increase to 20 %. The air void at the optimum plastic content is found 4.94 % due to increased compaction whch can fall under the limit of (3-5) %. But for others suggested plastic content the VA value is out of the required limit.The value of VA is calculated by using equation (3.10).

4.3.6 Plastic (PET) effects on Voids filled by Asphalt of dry modified HMA

The intergranular space of the aggregate in the compacted paving mix filled by the asphalt binder is called Voids filled by asphalt (VFA). The main effect of VFA is to limit the maximum level of bitumen in hot mix asphalt design. As shown in the figure 4.7 below the value of VFA goes increase from 10% to 14.3 % and gets decrease after this . Decreasing of the VFA value indicates the intergranular voids in the aggregate are coated or filled by the plastic beyond the limit whereas increasing value of the VFA indicates the intergranular space of the aggregate in the compacted paving mix is excessively filled by bitumen. Therefore the optimum plastic can fall between 10% and 15% plastic content. In this study 14.3 % plastic content is the optimum one. Because its VFA value is 70.39 % and it is between in 65% and 73 %. The VFA value is calculated by using equation (3.11).

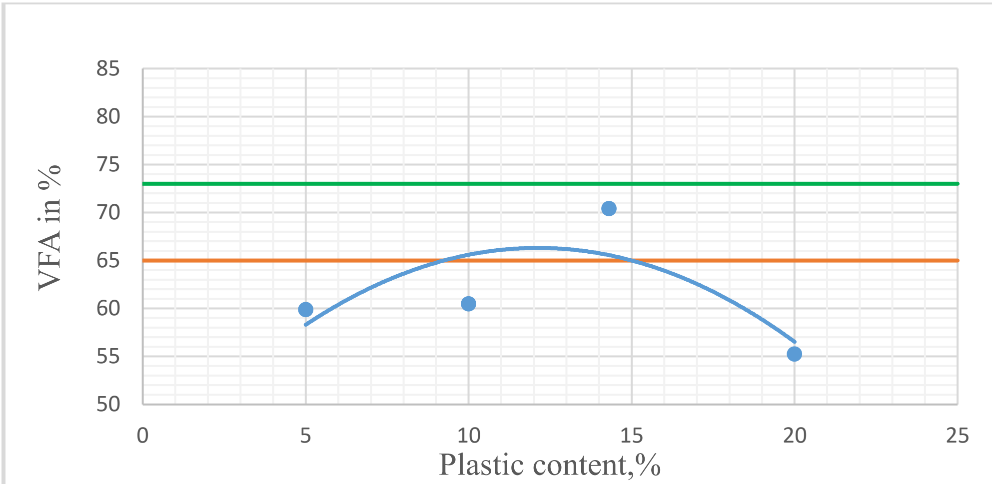


Figure 4. 7 Effect of plastic on VFA in dry mix process

4.4 Evaluation of rut resistance performance for plastic modified dry hot mix asphalt

Rutting is the defects of compacted paving mix due to a high frequency of loads. It is one of the basic flexible pavement distress. So giving a better attention for this type of distress in the flexible pavement is mandatory.

In this study rutting performance is evaluated in terms of wheel tracking depth (rut) and wheel tracking rate. To prepare a specimen for rutting performance test, 14.3 % plastic content (OPC) by weight of OBC is used. The test is conducted at constant temperature of 60^{o}c for 6 hours to complete 10,000 cycles or 20,000 passes. Table 4.9 below shows its test result.

Table 4. 10 Wheel tracking depth and wheel tracking rate test result in dry mix process

Trial No.	**Dry Modified mix**	
	Wheel tracking depth	**Wheel tracking rate**
1	1.31 mm	0.065mm/1000pass or 0.218mm/hr
Specification (AASHTO T 324-11)	$\leq 12mm$	$\leq \frac{0.5mm}{1000} pass$
Specification (ERA 2013)	$\leq 7mm$	$\leq 5mm/hr$

As shown from the table 4.10 above the wheel tracking depth and wheel tracking rate are within the specification limit for AASHTO T 324-11 and ERA flexible pavement design manual standard technical specifications of 2013. It indicates the compacted paving mix is almost stiff because when evaluated with AASHTO T324-11 the wheel tracking depth and wheel tracking rate is found 1.31 mm and 0.0655mm/1000 pass respectively at the end of 10,000 cycles. On the other hand when checked with ERA 2013 flexible pavement design manual standard technical specifications the wheel tracking depth and wheel tracking rate is 1.31 mm and 0.218mm/hr respectively at the end of 10,000 cycles. The dry modified mix has less value of wheel tracking depth and wheel tracking rate from wet mix and conventional one due to high content of plastic which can lead to an increase in the stiffness of the hot mix asphalt.

4.5 Evaluation of Moisture resistance performance for plastic Modified dry hot mix asphalt

Moisture causes adhesion loss between aggregate and the binder. Stripping of the compacted paving mix is then results of the moisture entrapping in to the compacted paving mix.

To evaluate Moisture resistance of the dry modified hot mix asphalt, indirect tensile strength is conducted for both conditioned and unconditioned Marshall designed gyratory compacted specimens. A tensile strength ratio of dry modified hot mix asphalt is calculated by dividing the average of three conditioned indirect tensile strength to the average of three unconditioned indirect tensile strength. Based on Ms-2 manual a TSR value should be at least 0.8 or 80%. If the TSR value is above 80% the compacted paving mix is less susceptible to the moisture and this indicates the adhesive bond between aggregate and asphalt is stronger or less strippable where as if the TSR value is under 80% the compacted paving mix is susceptible to the moisture. Table 4.11 below shows the average indirect tensile strength for unconditioned and conditioned dry modified compacted paving mix is 824.3 KN and 743.3 KN respectively. As AASHTO T 283 describes the average indirect tensile strength for unconditioned compacted paving mix is greater than 800 KN. Therefore 824.3 KN is greater than 800 KN and satisfies the specifications. Dividing indirect tensile strength of conditioned (743.3 KN) to indirect tensile strength of unconditioned (824.3 KN) results 0.902 or 90.2 %. So 90.2 % is greater than the minimum requirement of 80 %. This shows the compacted paving mix is not susceptible to moisture damage.

Table 4. 11 Indirect tensile strength and TSR test result of dry mix process

Specimen condition	Specimen No.	specimen height (mm)	Diameter of the specimen	Maximum load applied (KN)	Ring factor	ITS	TSR
Dry	1	90	150	140	123.36	814.8	**90.2 %**
	2	90	150	155	123.36	901.7	
	3	90	150	130	123.36	756.3	
	Average ITS of dry Specimen					**824.3**	
Wet	1	90	150	150	123.36	872	
	2	90	150	120	123.36	698	
	3	90	150	115	123.36	669	
	Average ITS of wet specimen					**743.3**	

4.6 Evaluation of Marshall Properties of plastic (PET) Modified HMA in the wet process

Evaluation for Marshall Properties of plastic modified hot mix asphalt in the wet process means evaluating the plastic effect on the Marshall properties of plastic modified hot mix asphalt in the wet process. The difference between dry and wet plastic modified hot mix asphalt is the plastic content suggested and in the dry process plastic and aggregate are mixed at high temperature before the bitumen is added but in the wet process the plastic and bitumen first mix vigorously before the aggregate is added. In the wet process the suggested plastic contents are 2 %. 4 %, 6 %, 8% and 10% by weight of OBC.

4.6.1 Plastic (PET) effects on the stability of wet modified HMA

The effect of plastic content on the stability of wet modified hot mix asphalt is shown in the figure 4.8 below. At the beginning the stability is low and increases to the peak point of 19.14 KN at 4%. After 4 % plastic content, the stability begins decrease. The suggested plastic content are 2 %, 4%, 6%, 8% and 10% and at these plastic contents the stability is greater than the minimum required value. But the optimum plastic content is 2 %. At 2 % plastic content all Marshall Criteria's are within the specification limit and its stability value is 16.42 KN which is above the minimum limit.

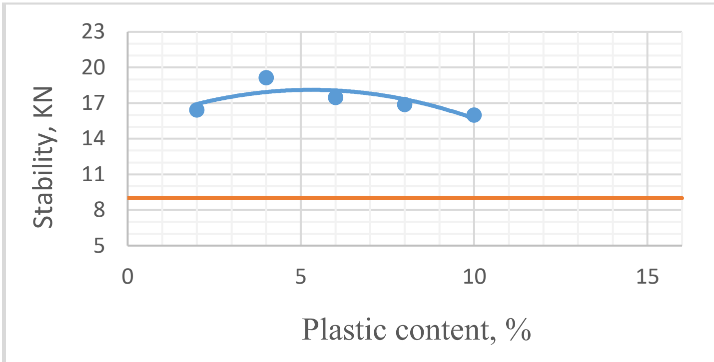


Figure 4. 8 Effect of plastic on stability in wet mix process

4.6.2 Plastic (PET) effects on the flow of wet modified HMA

The plastic effect on the flow value of the wet modified mix also evaluated by using the suggested plastic content of 2 % 4%, 6%, 8% and 10% by weight of OBC (5%). Figure 4.9 below shows the plastic effect on the flow value of wet modified hot mix asphalt.

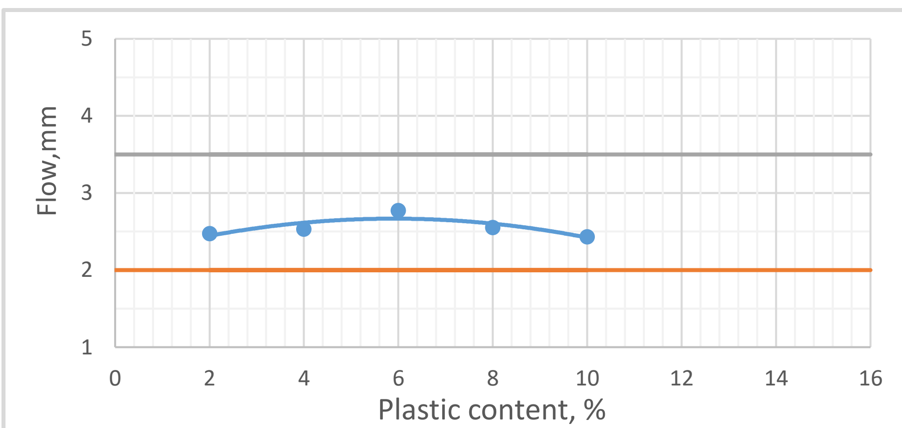


Figure 4. 9 Effect of plastic on flow value in wet mix process

As shown from the figure 4.9 above the flow value is within the specification limit of (2-3.5)mm for all suggested plastic content but except 2 % plastic content, others fail to fulfill the rest Marshall properties.

4.6.3 Plastic (PET) effects on the bulk specific gravity of wet modified HMA

The mix specific gravity is also affected when the plastic added as partial binder to the mix at different content. The logic is that if the specific gravity of the hot mix asphalt increases the mix is then dense and it in turns has a role in the performance of the road. Figure 4.10 below shows as the plastic content increases the specific gravity of the wet modified mix decreases. Therefore using optimum content of plastic is very crucial to keep the specific gravity high as much as possible. In this study the specific gravity of the hot mix asphalt at the optimum plastic content (2%) is recorded as 2.199 g/cm^3.

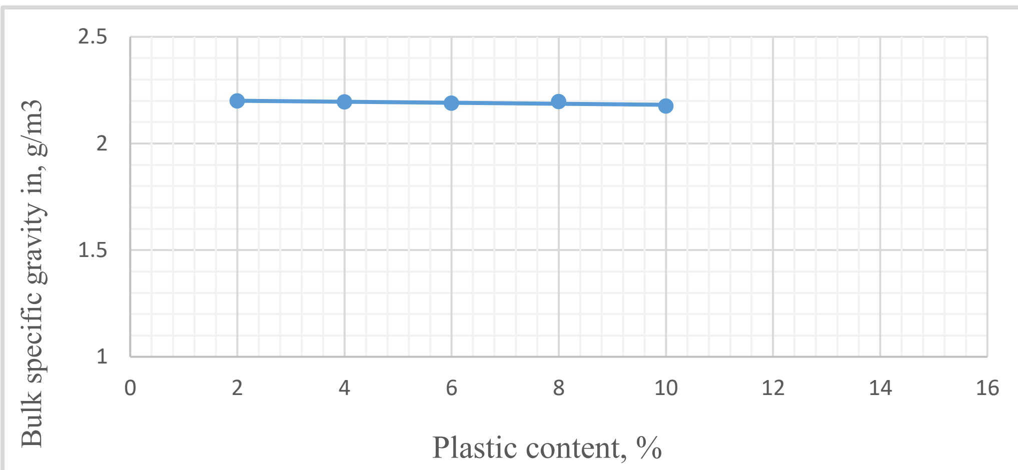


Figure 4. 10 Effect of plastic on specific gravity in wet mix process

4.6.4 Plastic (PET) effects on the VMA of wet modified HMA

The voids filled by mineral aggregate also evaluated as dry modified hot mix asphalt. The VMA is evaluated at the same plastic content of (2%, 4%, 6%, 8% and 10%). The minimum limit for the VMA is 14 %. For the value above 14 % VMA is acceptable as ERA 2013 standard technical specification for heavy traffic wearing coarse. Figure 4.11 shows as the plastic content increases the Value of VMA increases. All values of VMA for the suggested plastic contents can meet the requirements. But only 2 % plastic content fulfill all other Marshall properties. The VMA value at 2% plastic content is found 17.01 % which is greater than 14 %.

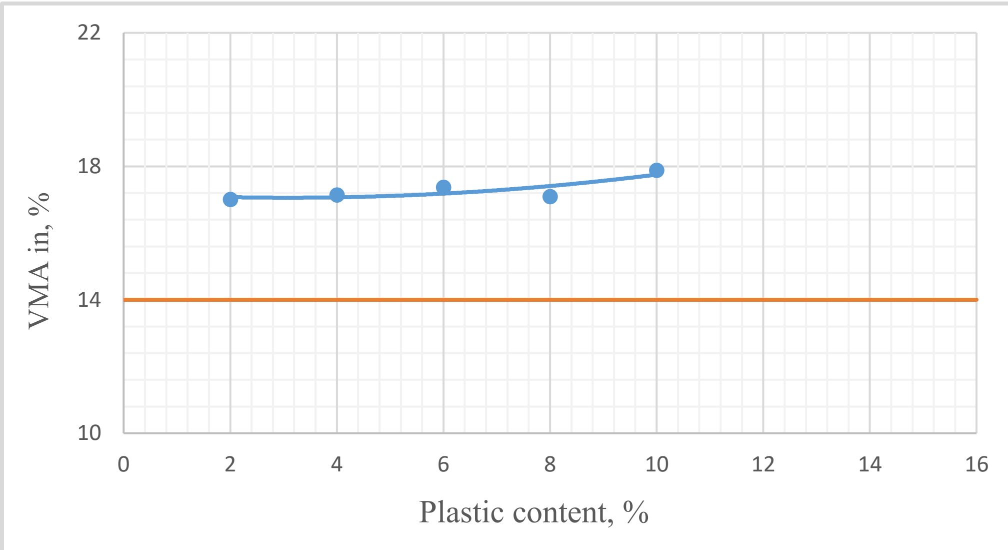


Figure 4. 11 Effect of plastic on VMA in wet mix process

4.6.5 Plastic (PET) effects on the VA of wet modified HMA

The voids filled by the air in the compacted paving mix also evaluated as other criteria by using the same plastic content of (2%, 4%, 6%, 8%and 10%). According to ERA 2013 standard technical specification, the upper and lower limit of the air void in heavy traffic wearing course is 5% and 3 % respectively. The air void in the wet modified HMA is also calculated as dry modified HMA by using equation 3.10. As shown in figure 4.12 below the air voids for 2 %, 4%, 6%, 8% and 10% plastic contents are 4.85%, 5.95%, 6.54%, 6.94% and 7.00 % respectively .Only at 2 % plastic content of wet modified hot mix asphalt fulfill the limit set in the standards. This implies as the plastic content that replace partially the bitumen increases the air void of the compacted paving mix increases. Therefore optimum plastic content for this wet modified hot mix asphalt is 2 %. Because at this plastic content the compacted paving mix air void is found 4.85 % which is within the limit set in the standards.

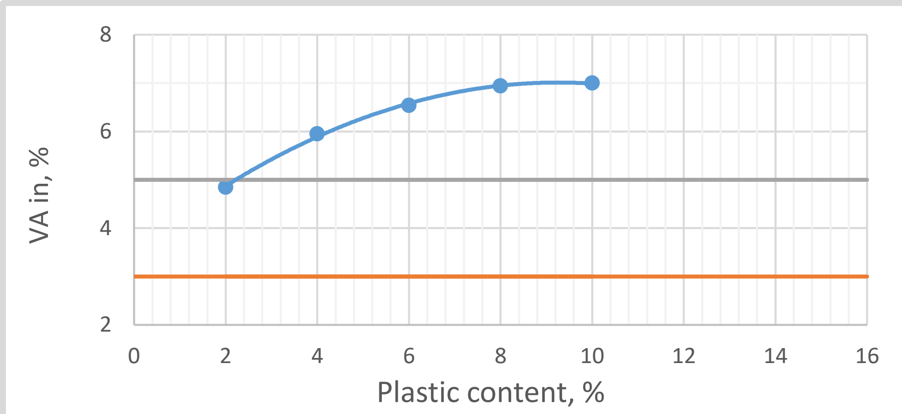


Figure 4. 12 Effect of plastic on VA in wet mix process

4.6.6 Plastic (PET) effects on the VFA of wet modified HMA

The last Marshall criteria that evaluated in wet modified hot mix asphalt is voids filled by asphalt. To evaluate the VFA of the compacted paving mix equation 3.11 is applied. As shown in figure 4.13 below as the plastic content increases forward the VFA value decreases. This shows addition of more plastic results a loose bond between aggregate and bitumen. Only at 2% and 4% plastic content can fulfill the criteria which is 71.53 % and 65.33% respectively. But addition of 4 % plastic content cannot fulfill other Marshall properties and therefore the VFA value for this study is 71.53 % at 2 % plastic content.

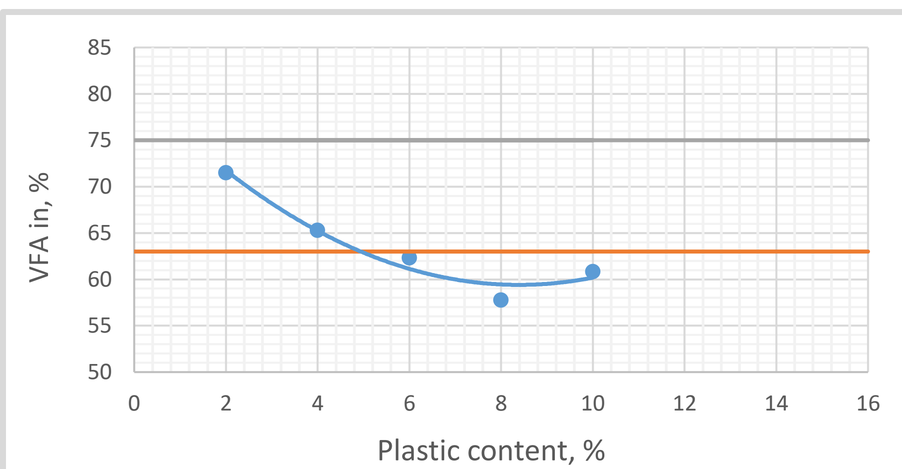


Figure 4.13 Effect of plastic on VFA in wet mix process

4.7 Evaluation of rut resistance performance for plastic modified wet hot mix asphalt

In this study rutting resistance performance is also evaluated for wet modified HMA in terms of wheel tracking depth (rut) and wheel tracking rate as the dry modified HMA. To prepare a specimen for rutting performance test, 2 % plastic content (OPC) by weight of OBC is applied. The test is conducted at constant temperature of 60^{o}c for 6 hours to complete 10,000 cycles or 20,000 passes. Table 4.12 below shows the wheel tracking depth and wheel tracking rate test result.

Table 4. 12 Wheel tracking depth and wheel tracking rate result in wet mix process

Trial No.	**Wet Modified mix**	
	Wheel tracking depth	**Wheel tracking rate**
1	2.39 mm	0.12mm/1000 pass or 0.398mm/hr
Specification (AASHTO T 324-11)	$\leq 12mm$	$\leq \frac{0.5mm}{1000} pass$
Specification (ERA 2013)	$\leq 7mm$	$\leq 5mm/hr$

As shown from the table 4.12 above the wheel tracking depth and wheel tracking rate are within the specification limit for AASHTO T 324-11 and ERA flexible pavement design manual standard technical specifications of 2013.It indicates that the compacted paving mix is almost stiff because when evaluated with AASHTO T324-11 the wheel tracking depth and wheel tracking rate is found 2.39 mm and 0.12mm/1000 pass respectively at the end of 10,000 cycles. On the other hand when evaluated with ERA 2013 flexible pavement design manual standard technical specifications, the wheel tracking depth and wheel tracking rate is 2.39 mm and 0. 12mm/hr respectively at the end of 10,000 cycles. The wet modified mix has slightly high value of wheel tracking depth and wheel tracking rate from dry modified HMA due to less content of plastic which can lead to a decrease in the stiffness of the hot mix asphalt relative to dry modified mix.

4.8 Evaluation of Moisture resistance performance for plastic Modified wet hot mix asphalt

To evaluate Moisture resistance of the wet modified hot mix asphalt indirect tensile strength is conducted for both conditioned and unconditioned Marshall designed gyratory compacted specimens as dry modified HMA. A tensile strength ratio of dry modified hot mix asphalt is calculated by dividing the average of three conditioned indirect tensile strength to the average of three unconditioned indirect tensile strength. Based on Ms-2 manual a TSR value should be at least 0.8 or 80%. If the TSR value is above 80% the compacted paving mix is less susceptible to the moisture and this indicates the adhesive bond between aggregate and asphalt is stronger or less strippable where as if the TSR value is under 80% the compacted paving mix is susceptible to the moisture. Table 4.13 below shows the average indirect tensile strength for unconditioned and conditioned wet modified compacted paving mix is 1056.8 KN and 888.1 KN respectively. As AASHTO T 283 describes the average indirect tensile strength for unconditioned compacted paving mix is greater than 800 KN and not more than 1200 kN. Therefore 1056.8 KN is greater than 800 KN and less than 1200 KN which can satisfy the specifications. Dividing indirect tensile strength of conditioned (888.1 KN) to indirect tensile strength of unconditioned (1056.8 KN) results 0.84 or 84 %. So 84 % is greater than the minimum requirement of 80 %. This indicates the compacted paving mix is not susceptible to moisture damage.

Table 4. 13 Indirect tensile strength and TSR result of wet mix process

Specimen condition	Specimen No.	specimen height (mm)	Diameter of the specimen	Maximum load applied (KN)	Ring factor	ITS	TSR
Dry	1	90	150	197	123.36	1146	84 %
	2	90	150	180	123.36	1047.1	
	3	90	150	168	123.36	977.3	
		Average ITS of dry Specimen				**1056.8**	
Wet	1	90	150	163	123.36	948.21	
	2	90	150	144	123.36	837.69	
	3	90	150	151	123.36	878.41	
		Average ITS of wet specimen				**888.1**	

4.9 Optimization of dry and wet processes performances

In this study after evaluation of the Marshall Properties, rut resistance performance and moisture sensitivity performance for both the dry and wet processes, optimization of these processes are established. To establish optimization a special type of Multi-criteria decision analysis Method of TOPSIS is applied. The selected criteria's to optimize the dry and wet processes are stability, bulk specific gravity, VMA, rut resistance performance (wheel tracking depth and wheel tracking rate) and moisture sensitivity as TSR and their corresponding weightage based on relative importance is assumed 0.2, 0.1, 0.1, 0.2, 0.2 and 0.2 respectively using subjective approach. To weight the criteria's based on their relative importance, subjective and objective approaches are applied. Objective uses mathematical model whereas the subjective follows a direct assumption of weights for the criteria's without decision matrix (Slebi-Acevedo & Castro-Fresno, 2019). A decision matrix i*j is formed where i represents alternative and row of the Matrix whereas j represents criteria's and column of the matrix. The first row represents dry process and the second row represents wet process as shown from table 3.3 below.

$$\text{Decision Matrix } (x_{ij}) = \begin{bmatrix} 21.26 & 2.207 & 16.69 & 1.31 & 0.000065 & 90.2 \\ 16.42 & 2.199 & 17.01 & 2.39 & 0.00012 & 84 \end{bmatrix}$$

This decision matrix (x_{ij}) is normalized as (R_{ij}) by using equation 3.12 to eliminate the dimension of the criteria's.

$$\text{Normalized decision Matrix } (R_{ij}) = \begin{bmatrix} 0.79 & 0.71 & 0.7 & 0.48 & 0.477 & 0.73 \\ 0.611 & 0.7 & 0.71 & 0.87 & 0.88 & 0.681 \end{bmatrix}$$

After normalized the decision matrix the weighted normalized decision Matrix (V_{ij}) is calculated by using equation 3.13 as shown below.

$$\text{Weighted normalized decision matrix } (V_{ij}) = \begin{bmatrix} 0.16 & 0.071 & 0.07 & 0.096 & 0.095 & 0.15 \\ 0.12 & 0.07 & 0.071 & 0.17 & 0.18 & 0.14 \end{bmatrix}$$

From weighted normalized decision Matrix ideal solution (A^+) the highest value to benefit or Maximization and negative ideal solution (A^-) the worst value to benefit or maximization is selected to calculate the ideal Euclidean distance (D^+) and negative Euclidean distance (D^-).

Therefore the ideal solution (A_j^+): [0.16, 0.071, 0.071, 0.096, 0.095, 0.15] and the Negative ideal solution (A_j^-): [0.12, 0.07, 0.07, 0.096, 0.095, 0.14]. Based on these ideal solutions the results of D^+, D^- and C_i are organized in the table 4.14 below.

Table 4. 14 Closeness coefficient of dry and wet processes

Alternatives	**Ideal Euclidean distance (D^+)**	**Negative ideal Euclidean distance (D^-)**	**Closeness Coefficient (C_i)**
Dry process	0.001	0.0412	0.97
Wet process	0.12	0.114	0.49

As shown from table 4.14 above the ideal Euclidean distance, Negative ideal Euclidean distance to ideal solution and closeness coefficient of the alternatives are computed by using equation 3.14, equation 3.15 and equation 3.16 respectively. The closeness coefficient of the dry process is 0.97 and the closeness coefficient of the wet process is 0.49. Therefore based on Multi-criteria decision analysis method of TOPSIS the alternative that has high value is selected. The closeness coefficient, from TOPSIS results for TRITOR as 0.6320, Eco Energy as 0.5820, Green Team as 0.4869 and Global Industry Benchmarks as 0.4355 were found. Based on this comparative analysis, a Multi-criteria decision method of TOPSIS is used and rank the TRITOR as first from the three companies with a closeness coefficient of 0.6320. This result high lights the TRITOR's ability to balance economic, environmental, and operational criteria effectively in the waste management practice (Matarazzo1 et al., 2024). In this study therefore, dry process has greater value of 0.97 and selected for its performance from wet process.

4.10 Cost comparison of dry and wet processes

A simple cost analysis is executed to determine cost effective process. As shown from figure 3.25 above 1Km*7m*5cm road section is taken and evaluated its cost in terms of bitumen for conventional mix. The volume of this hot mix asphalt is 350 m^3 and its density from table 3.2 is 2238 kg/m^3. The total cos of bitumen for the reference mix is analyzed after total weight analyzation of conventional the asphalt mix. 5 % of the total weight of the mix is the bitumen and it measures 39,165 Kg. The total cost of bitumen for conventional mix is shown in table 4.15 below.

Table 4. 15 Total cost of bitumen for 1 km conventional mix road section

volume (m^3)	**Asphalt weight (Kg)**	**Bitumen weight (5 %)**	**drums required 1Drums=182kg**	**Unit rate**	**Bitumen cost 60/70 ETB**
350	783,300	39,165	215.2	30,000	6456000

Based on the above table of 4.15 the total weight and cost of bitumen used in the conventional mix, determination of the weight and cost of dry and wet processes is then established. Now cost of waste plastic is 60birr/kg and its processing cost is 20 birr/kg. Then a total cost of plastic is 80 birr/kg. As shown table 4.16 below the optimum plastic content by weight of OBC (5%) for dry process is 14.3% and that of wet process is 2 %. The weight of bitumen replaced by plastic in the dry process is 5600.6 kg and for that of wet process is 783.3 kg for this section of road. The total cost of binder for dry modified hot mix asphalt is 5,979,461.12 ETB. On the other hand the total cost of binder for wet modified hot mix asphalt is 6,387,968 ETB. From this analysis, dry process has low cost and it is cost effective than wet process.

Table 4.16 Cost comparison of dry and wet processes

Description	Conventional mix Bitumen	Dry (14.3%)plastic by weight of OBC		Wet (2%) plastic by weight of OBC	
		Bitumen	Plastic	Bitumen	Plastic
Weight (kg)	39,165	33,564.405	5,600.6	38,381.7	783.3
Unit rate (birr/kg)	164.841	164.841	80	164.841	80
Cost (ETB)	6,456,000	5,532,790.1	448,048	6,326,877.81	62,664
Total cost	**6,456,000**	**5,979,461.1**		**6,387,968**	

The film and Pe-Cu mixtures demonstrated environmental and economic advantages. But the Film mixture performing slightly less than Pe-Cu from the mechanical perspective, Pe-Cu is the material that awards the greatest benefits. In deed, 17% reduction in environmental impact and 11% in economic impact can be achieved when the wearing course is considered only (Pedro Lastra-

González & Flintsch, 2020). As shown in the above table of 4.16 the cost of conventional mix bitumen reduced by 7.831 % when dry process is applied and 1.05 % cost reduction is observed from wet process. So in this study, Dry process is attractive not only in its cost effectiveness but also for its performance.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

A conclusion is now drawn from the aligned objectives, Methodologies and findings in this study. In this section material characterization test results, Marshall Properties of dry and wet processes, optimum plastic content applied for dry and wet processes, optimization and cost reduction value are narrated. It also generalize the dry process as a higher performance of plastic modified hot mix asphalt and cost effective for its application in road construction practices.

From the recommendation part, the future lines to be addressed are presented. It also points a good insight to use the best processes in the application of plastic in asphalt road construction practices. The findings of this study is therefore concluded as shown below.

1. From Material characterization; six basic aggregate tests are checked. Combined gradation of the aggregate is within the limit. The bulk specific gravity, water absorption, ACV, Flakiness index and soundness are 2.157 g/cm3, 1.58 %, 16.45%, 13.3 % respectively. Soundness test for course and fine aggregate is 5.08 % and 3.04 % respectively. All the experiment result are found within the specification limit
2. In this study the basic Bitumen quality tests of specific gravity, ductility, penetration and softening point of the bitumen are established and the findings of the result are 1.024, 125, 62.9 and 50.1^{o}c respectively
3. To establish dry and wet processes a reference mix is mandatory. In this study a conventional hot mix Asphalt is designed first as a procedure to determine the optimum plastic content. The optimum bitumen content is found as 5 % which helps for OPC determination dry and wet processes.
4. The Marshall properties of dry and wet process is evaluated through their respective optimum plastic content of 14.3 % and 2 % by the weight of OBC.
5. Dry process has good Marshall Property's performance in stability and bulk specific gravity whereas wet process has greater value of VMA. In both processes VA and VMA goes increases as the plastic content increases. In most causes as the plastic increases the flow and VFA values are going decreases.

6. Dry modified hot mix asphalt is very interesting that it has low wheel tracking depth (rut) of 1.31mm in 10,000 cycles and wheel tracking rate of 0.000065 mm/pass
7. Wet modified hot mix asphalt has high wheel tracking depth and wheel tracking rate resistance than dry modified which is 2.39 mm and 0.00012 mm/pass
8. Dry modified hot mix asphalt has TSR value of 90.2 % and that of wet modified hot mix asphalt 84 %. Here dry modified hot mix asphalt is less susceptible to striping or moisture.
9. Based on Multi-criteria decision analysis method of TOPSIS the closeness' coefficient of dry and wet processes are 0.97 and 0.487respectively. And dry process is more attractive alternative than wet process.
10. From simple cost analysis dry process has 7.831 % cost reduction and that of wet process is 1.05 % from the conventional hot mix asphalt bitumen cost. Therefore dry process is the better alterative relative to cost.

5.2 Recommendations

Based on the findings of this study the following ideas should be reminded.

1. The optimum plastic content in dry and wet processes should not out (12-15) and (2-6) percent respectively.
2. This experimental investigation is only done through PET plastic. Therefore future researchers should better focus on other type of plastics.
3. It is better to practice Dry process than the conventional and wet process in road construction practices. Because it's performance in Marshall Properties and other low flexible pavement distress susceptibility.
4. Asphalt plant manufacturers should design their asphalt plant as it can mix plastic and bitumen for both dry and wet process for tomorrow.
5. The physical properties of the plastic coated aggregate should the future studies that influence in Marshall Properties of the hot mix.
6. The central laboratories of the projects should also organized as it can mix the asphalt and plastic.
7. Care should take when melting the plastic. Because the gases those generate during mixing causes health problems.

REFERENCES

Abiyot Mihret , Ashenafi Aysa , & Nigussie, C. (2018). Improve the quality of bitumen using PET bottle plastic as an excellent additive Bahir Dar].

Adedayo A. Badejo1, Adebola A. Adekunle1, , O. O. A., , J. M. N., , K. W. K., , & Omole, B. S. B. a. D. O. (2017). Plastic waste as strength modifiers in asphalt for a sustainable environment. African Journal of Science, Technology, Innovation and Development. https://doi.org/ 10.1080/20421338.2017.1302681

Akshar Patel, Shweta J Chahan, 3Brijen Prajapati, & Kanojia, N. (2018). Cost Comparison Plastic Road with Regular Bitumen Road. International Journal for Research Trends and Innovation 3(4).

Alvarez, A. E., , E. O., & , S. C. (2012). Assessment of the effect of mineral filler on asphalt–aggregate interfaces based on thermodynamic properties. Construction and Building Materials. https://doi.org/doi:10.1016/j.conbuildmat.2011.08.089

Bahia, A. F. F. H. U. (2010). Modelling of Asphalt Mastic in Terms of Filler-Bitumen Interaction. In. https://doi.org/DOI:10.3166/RMPD.11HS.281-303

BAOSHAN HUANG*, X. S. a. X. C. (2006). Effects of mineral fillers on hot-mix asphalt laboratory-measured properties. INTERNATIONAL JOURNAL OF PAVEMENT ENGINEERING. https://doi.org/DOI: 10.1080/10298430600819170

Behiry, A. E. A. E.-M. (2015). Optimisation of hot mix asphalt performance based on aggregate selection. International Journal of Pavement Engineering. https://doi.org/ DOI: 10.1080/10298436.2015.1043634

Bessa, I. S., Branco, V. T. F. C., Soares, J. B., & Neto, a. J. A. N. (2014). Aggregate Shape Properties and Their Influence on the Behavior of Hot-Mix Asphalt. Journal of Materials in Civil Engineering. https://doi.org/DOI: 10.1061/ (ASCE)MT.1943-5533.0001181

Chen, M.-z., , J.-t. L., , S.-p. W., & , C.-h. L. (2011). Utilization of recycled brick powder as alternative filler in asphalt mixture. Construction and Building Materials. https://doi.org/ doi:10.1016/j.conbuildmat.2010.08.005

Chen, M., , J. L., & , S. W. (2011). tential of recycled fine aggregates powder as filler in asphalt mixture. Construction and Building Materials. https://doi.org/doi:10.1016/j.conbuildmat.2011.04.022

Costa, L. M. B., , H. M. R. D. S., , J. R. M. O., & , a. S. R. M. F. (2013). Incorporation of Waste Plastic in Asphalt Binders to Improve their Performance in the Pavement. International Journal of Pavement Research and Technology. https://doi.org/DOI:10.6135/ijprt.org.tw/2013.6(4).457

El-Naga, I. A., & , M. R. (2019). Benefits of utilization the recycle polyethylene terephthalate waste plastic materials as a modifier to asphalt mixtures. Construction and Building Materials. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.05.172

Esat Gashi, H. S., Misin Misini. (2017). A Review of Aggregate and Asphalt mixture Specific Gravity measurements and their Impacts on Asphalt Mix Design Properties and MixAcceptance. International Journal of Advanced Engineering Research and Science (IJAERS) https://doi.org/https://dx.doi.org/10.22161/ijaers.4.5.31

Esmaeil Ahmadinia, M. Z., & , M. R. K., Mahrez Abdelaziz, Ebrahim Ahmadinia. (2012). Performance evaluation of utilization of waste Polyethylene Terephthalate (PET) in stone mastic asphalt. Construction and Building Materials. https://doi.org/http://dx.doi.org/10.1016/j.conbuildmat.2012.06.015

F. Pinto *, P. C., I. Gulyurtlu, I. Cabrita. (1998). Pyrolysis of plastic wastes. 1. Effect of plastic waste composition on product yield. Journal of Analytical and Applied Pyrolysis.

Ferreira, J. L. S., , L. F. A. L. B., , J. B. S. B., & , J. B. S. (2020). A tool to design rutting resistant asphalt mixes through aggregate gradation selection. Construction and Building Materials.https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.117531

Fucheng Guo, J. P., & , J. Z., Bin Xue, Guoqing Sun, Rui Li. (2020). Study on the adhesion property between asphalt binder and aggregate: Astate-of-the-art review. Construction and Building Materials. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2020.119474

Gentzis, P. M. R. a. T. (2000). THE CHEMISTRY OF BITUMEN AND HEAVY OIL PROCESSING In FRACTIONAL COMPOSITION OF BITUMEN/ HEAVY OIL.

Gilbert, P. M. (2017). Plastics Materials: Introduction and Historical Development. Brydson's Plastics Materials. https://doi.org/ http://dx.doi.org/10.1016/B978-0-323-35824-8.00001-3

Grady, B. P. (2021). Waste plastics in asphalt concrete: A review. Wiley Periodicals LLC. on behalf of Society of Plastics Engineers., 15. https://doi.org/DOI: 10.1002/pls2.10034

H. Naghawi, R. A.-A., R. Allouzi, A. AlKlub, K. Masarwah, A. AL-Quraini, M. Abu-Sarhan. (2018a). Plastic Waste Utilization as Asphalt Binder Modifier

in Asphalt Concrete Pavement International Journal of Civil and Environmental Engineering, 12.

H. Naghawi, R. A.-A., R. Allouzi, A. AlKlub, K. Masarwah, A. AL-Quraini, M. Abu-Sarhan. (2018b). Plastic Waste Utilization as Asphalt Binder Modifier in Asphalt Concrete Pavement. International Journal of Civil and Environmental Engineering, 12.

Haddock, M. R. P. J. E. (2019). A new framework for understanding aggregate

structure in asphalt mixtures. International Journal of Pavement Engineering. https://doi.org/International Journal of Pavement Engineering

Hafiz Muhammad Zahid Hassan, K. W., Wenke Huang, Sihang Chen, Qiran Zhang, Jiawen Xie,, & Cai, X. (2021). Study on the influence of aggregate strength and shape on the

performance of asphalt mixture. Construction and Building Materials. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2021.123599

Halden, R. U. (2010). Plastics and Health Risks. https://doi.org/10.1146/annurev.publhealth.012809.103714

Hanaa Khaleel Alwan Al-Bayatia, & , S. L. T., Jessica Achebe. (2018). Influence of recycled concrete aggregate on volumetric properties of hot mix asphalt. Resources, Conservation & Recycling. https://doi.org/https://doi.org/10.1016/j.resconrec.2017.11.027

Hattatoglu, S. A. E. Y. F., & Akbuluta, S. H. S. (2013). Correlation between Shape of Aggregate and Mechanical Properties of Asphalt Concrete. Road Materials and Pavement Design. https://doi.org/http://dx.doi.org/10.1080/14680629.2011.9695245

Hu¨seyin Akbulut, C. G. r. (2006). Use of aggregates produced from marble quarry waste in asphalt pavements. Building and Environment. https://doi.org/ doi:10.1016/j.buildenv.2006.03.012

Jian-Shiuh Chen, W. H., & , a. M.-C. L. (2013). Effect of Coarse Aggregate Shape on Engineering Properties of Stone Mastic Asphalt Applied to Airport Pavements. International Journal of Pavement Research and Technology. https://doi.org/DOI:10.6135/ijprt.org.tw/2013.6(5).595

João Pinto da Costa ⁎, P. S. M. S., Armando C. Duarte, Teresa Rocha-Santos. (2016). (Nano)plastics in the environment – Sources, fates and effects. Science of the Total Environment.https://doi.org/http://dx.doi.org/10.1016/j.scitotenv.2016.05.041

Joseph, B., , J. J., , N. K., & , S. T. (2021). Recycling of medical plastics. Advanced Industrial and Engineering Polymer Research. https://doi.org/ http://www.keaipublishing.com/aiepr https://doi.org/10.1016/j.aiepr.2021.06.003

Lastra-González, P., , E. L.-A., & , D. C.-F. a. G. F. (2020). Analysis of replacing virgin bitumen by plastic waste in asphalt concrete mixtures. INTERNATIONAL JOURNAL OF PAVEMENT ENGINEERING. https://doi.org/ https://doi.org/10.1080/10298436.2020.1866760

Lastra-González, P., , M. A. C.-P., , D. C.-F., , Á. V.-Z., , & Indacoechea-Veg, I. (2016). Comparative analysis of the performance of asphalt concretes modified by dry way with polymeric waste. Construction and Building Materials. https://doi.org/http://dx.doi.org/10.1016/j.conbuildmat.2016.02.156

Lesueur, D. (2008). The colloidal structure of bitumen: Consequences on the rheology and on the mechanisms of bitumen modification. Advances in Colloid and Interface Science. https://doi.org/doi:10.1016/j.cis.2008.08.011

Loise, V., , P. C., Michele Porto , , P. C., & Rossi, R. A. a. C. O. (2019). A Review on Bitumen Rejuvenation: Mechanisms, Materials, Methods and Perspectives. Applied science. https://doi.org/doi:10.3390/app9204316

M. Reza Pouranian and John E. Haddock, M. A. (2020). Effect of Aggregate Gradation on Asphalt Mixture Compaction Parameters. https://doi.org/DOI: 10.1061/(ASCE)MT.1943-5533.0003315

Maria Mastalerz, , A. D., & , A. B. S. (2018). Origin, properties, and implications of solid bitumen in source-rock reservoirs: A review. International Journal of Coal Geology. https://doi.org/https://doi.org/10.1016/j.coal.2018.05.013

Martin-Alfonsoa, J. E., , A. A. C., & , J. T., M.E. Hidalgob and P. Partal a. (2019). Use of plastic wastes from greenhouse in asphalt mixes manufactured by dry process. Road Materials and Pavement Design. https://doi.org/DOI: 10.1080/14680629.2019.1588776

Mashaan, N. S., & , A. C., Hamid Nikraz, Alireza Rezagholilou. (2021). Investigating the engineering properties of asphalt binder modified with waste plastic polymer. Ain Shams Engineering Journal. https://doi.org/https://doi.org/10.1016/j.asej.2020.08.035

Masson*, J.-F. (2008). Brief Review of the Chemistry of Polyphosphoric Acid (PPA) and Bitumen. American Chemical Society.

Matarazzo1, A., , M. R. C., Salvatore Ingenito1, , Zerbo1, A., , G. R., & , G. C. (2024). CIRCULAR ECONOMY INDICATORS APPLIED TO A WASTE MANAGEMENT TECHNIQUES BY A SICILIAN COMPANY.THE CASE STUDY TRITOR L.T.D. Environmental Science, Engineering and Management.

Md. Nobinur Rahman, , M. A., , M. A. S., & , T. U. A. (2013). Performance Evaluation of Waste Polyethylene and PVC on Hot Asphalt Mixtures. American Journal of Civil Engineering and Architecture. https://doi.org/DOI:10.12691/ajcea-1-5-2

Moghaddam, T. B., & , M. S., Mohamed Rehan Karim. (2014). Experimental characterization of rutting performance of Polyethylene Terephthalate modified asphalt mixtures under static and dynamic loads. Construction and Building Materials. https://doi.org/http://dx.doi.org/10.1016/j.conbuildmat.2014.05.006

Movilla-Quesada, D., , A. C. R., , L. T. S.-K., , P. L.-G., & , D. C.-F. (2019). Use of plastic scrap in asphalt mixtures added by dry method as a partial substitute for bitumen.WasteManagement.https://doi.org/https://doi.org/10.1016/j.wasman.2019.03.018

N, A., , K. M. M., & , M. I. A. (2014). INFLUENCE OF PARTICLE INDEX OF COARSE AGGREGATE AND ITS INFLUENCES ON PROPERTIES OF

ASPHALT CONCRETE MIXTURES. International Journal of Research in Engineering and Technology, 03(06).

Nasr, M. A. a. D. (2016). Performance properties of devulcanized waste PET modified asphalt mixtures. https://doi.org/ 10.1080/10916466.2016.1251457

Nigussie, C. (2018). Improve the quality of bitumen using PET bottle plastic as an excellent additive. 53.

Ongel, A., & , M. H. (2015). Impact of rejuvenators on aging properties of bitumen.Construction and Building Materials.https://doi.org/http://dx.doi.org/10.1016/j.conbuildmat.2015.07.030

Pedro Lastra-González, E. L.-A., Daniel Castro-Fresno &, & Flintsch, G. (2020). Analysis of replacing virgin bitumen by plastic waste in asphalt concrete mixtures. International Journal of Pavement Engineering. https://doi.org/ https://doi.org/10.1080/10298436.2020.1866760

Rajagopal, J. M. K. a. K. (2003). Review of the uses and modeling of bitumen from ancient to modern times. https://doi.org/@DOI: 10.1115/1.1529658#

Ramia Alajarmeh, A. A., Rabab Allouzi. (2018). Plastic Waste Utilization as Asphalt Binder Modifier in Asphalt Concrete Pavement. International Journal of Civil and Environmental Engineering, 15.

Slebi-Acevedo, P. P.-M., Pedro Lastra-González &, & Castro-Fresno, D. (2019). A multi-criteria decision-making analysis for the selection of fibres aimed at reinforcing asphalt concrete mixtures. International Journal of Pavement Engineering. https://doi.org/: https://doi.org/10.1080/10298436.2019.1645848

Sobhan, M. N. R. a. M. A. (2013). Use of Non-Conventional Fillers on Asphalt-Concrete Mixture. International Journal of Innovation and Applied Studies, 03.

TADEM, T. (2021). PERFORMANCE EVALUATION OF PLASTIC WASTE MODIFIED HOT MIX ASPHALT CONCRETE ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY].

Tan, M. G. a. Y. (2019). Interaction between asphalt and mineral fillers and its correlation to mastics' viscoelasticity. INTERNATIONAL JOURNAL OF PAVEMENT ENGINEERING. https://doi.org/DOI:10.1080/10298436.2019.1575379

TANDEM, T. (2021). PERFORMANCE EVALUATION OF PLASTIC WASTE MODIFIED HOT MIX ASPHALT CONCRETE.

Varanda, C., , I. P., , J. R., , A. M. S. S., & , C. M. S. (2017). Optimization of bitumen formulations using mixture design of experiments (MDOE). Construction and Building Materials. https://doi.org/http://dx.doi.org/10.1016/j.conbuildmat.2017.08.146

Xi Chen, Y. W., & Zhang, L. (2021). Recent Progresses in the Chemical Upcycling of Plastic Wastes. In.

Xu, T., & , X. H. (2011). Investigation into causes of in-place rutting in asphalt pavement. Construction and Building Materials. https://doi.org/ doi:10.1016/j.conbuildmat.2011.09.007

Yin, F., , M. F., , R. M., , M. D. E., , Tran, N., & , a. J.-P. P. (2021). Performance Evaluation of Asphalt Mixtures Modified with Recycled Polyethylene via the Wet Process. Journal of Transportation Research Record. https://doi.org/DOI: 10.1177/03611981211011650

Yu Chen , S. X., Gabriele Tebaldi & Elena Romeo. (2020). Role of mineral filler in asphalt mixture. ROAD MATERIALS AND PAVEMENT DESIGN. https://doi.org/ https://doi.org/10.1080/14680629.2020.1826351

Zulkati, A., Diew, W. Y., & Delai, a. D. S. (2012). Effects of Fillers on Properties of Asphalt-Concrete Mixture. JOURNAL OF TRANSPORTATION ENGINEERING. https://doi.org/DOI: 10.1061/(ASCE)TE.1943-5436.0000395

Appendix A: Material characterization

I. Asphalt Aggregate quality test result

Specific gravity and water absorption for coarse aggregate			
Test Data			
Description	**Test No.1**	**Test No.2**	
A. Mass of oven dry sample(gm)	2469.0	2786.0	
B. Mss of SSD Sample in air(gm)	2497.0	2815.0	
C. Mss of Saturated sample in Water (gm)	1499.5	1687.2	
Specific gravity	**Calculation**		**Average**
Bulk specific Gravity (oven Dry) A/(B-C)	2.475	2.470	**2.472**
Apparent specific Gravity A/(A-C)	2.547	2.535	**2.541**
Bulk specific Gravity (SSD) B/(B-C)	2.503	2.496	**2.500**
Water Absorption % (A=(B-A)*100/A)	1.13	1.04	**1.085**
Specific gravity and Water absorption for fine aggregate			
A. Mass of oven dry sample(gm)	1331.0	1343.0	
B. Mss of SSD Sample in air(gm)	1345.0	1358.0	
C. Mss of Saturated sample in Water (gm)	806.9	814.4	
Specific gravity	**Calculation**		**Average**
Bulk specific Gravity (oven Dry) A/(B-C)	2.474	2.471	**2.473**
Apparent specific Gravity A/(A-C)	2.540	2.541	**2.541**
Bulk specific Gravity (SSD) B/(B-C)	2.500	2.498	**2.500**
Water Absorption % (A=(B-A)*100/A)	1.05	1.12	**1.085**

Aggregate crushing value (ACV)

Description	Trials	
	1	2
Standard sieve size in (mm)	10-14	10-14
Duration of testing in (minute)	10	10
Standard applied load in (kN)	400	400
Mass of aggregate before test, passing through in 14mm and retain in10mm ,M1 (gm)	2638	2670
Mass of aggregate after test ,retained in 2.36mm, M2 (gm)	2208	2228
Mass of aggregate after test, pass in 2.36mm,M3 =[M1-M2] in (gm)	430	442
ACV(%) =(M1-M2)/M1*100	16.3	16.6
Average (ACV)%	**16.45**	
Specification	$\leq$ **30** %	

Aggregate flakiness Index

Sieve size in mm	*Slot thickness gauge (mm)*	**Trial- 1**		**Trial-2**	
		Weight retained on sieve (gm)	*Weight pass in gauge (gm)*	*Weight retained on sieve (gm)*	*Weight pass in gauge (gm)*
63	63-50	0	0	0	0
50	50-37.5	0	0	0	0
37.5	37.5-28	0	0	0	0
28	28-20	413	71	432	73
20	20-14	930	92	820	112
14	14-10	603	90	588	68
10	10-6.3	407	64	351	37
Total		2355	317	2191	290
Flakiness index, %		**13.5**		**13.2**	
Average		**13.3**			
Specification		$\leq$ **35%**			

Aggregate Soundness test result

Sieve size (mm)	Sieve size used (mm)	Weight (gm)	% Rt of grading sample (x)	Mass of test fraction (gm)		% passing after sieve (v=y-z/y*100)	% wt. loss= (w=v*x/100)
				Before test (y)	After test(z)		
63mm-50mm	31.5	**3000±300**					
50mm-37.5mm	31.5	**2000 ± 200**					
37.5mm-25mm	16	**1000 ± 50**					
25mm-19mm	16	**500 ± 50**	1.15	550	502	8.7	0.1
19mm-12.5mm	8	**670 ± 10**	27.64	680	610	10.3	2.8
12.5mm-9.5mm	8	**330 ±15**	16.67	345	327	5.2	0.9
9.5mm-4.75mm	4	**300 ± 5**	21.41	305	287	5.9	1.3
Total Loss on sodium sulphate (SSS) % Course Aggregate							**5.08**
4.75mm-2.36mm		**100**	13.80	100	90	10.0	1.38
2.36mm-1.18mm		**100**	8.51	100	89	11.0	0.94
1.18mm-0.600mm		**100**	4.70	100	91	9.0	0.42
0.600mm-0.300mm		**100**	3.00	100	90	10.0	0.30
Total Loss on sodium sulphate (SSS) % Fine Aggregate							**3.04**

II. Bitumen quality test

Specific gravity of Bitumen

Description	**Trial 1**	**Trial2**	**Trial3**
W1. Mass of pycnometer (gm)	70.70	70.70	70.00
W2. Mass of pycnometer+Bitumen (gm)	122.60	120.80	112.60
W3. Mass of pycnometer + Water (gm)	179.80	179.70	178.40
W4. Mass of pycnometer+ bitumen +Water (gm)	181.20	180.60	179.50
Specific gravity of bitumen $= \frac{W2-W1}{(W3-W1)-(W4-W2)}$	1.03	1.02	1.03
Average specific gravity of bitumen	**1.024**		

Ductility test result for Bitumen

Ductility (cm)		Average	specification
A	**130**	**125**	≥ 100
B	**120**		

Penetration value of Bitumen (60/70)

Specimen	Penetration value (10^{th} of mm)			Average	Specification
	Reading 1	Reading 2	Reading 3		
A	63.1	61.4	63.9	**62.8**	**60-70**
B	65.9	66.3	65.5	**65.9**	**60-70**

Bitumen (60/70) Softening point result

Softening point		Average	Specification	
Ball A	**Ball B**		**Lower**	**Upper**
50^{o}c	50.2^{o}c	**50.1^{o}c**	**46**	**56**

Appendix B: Dry modified Marshall Mix Design Results

I. Aggregate proportioning for dry and wet (Preparation of laboratory batch by weight)

Sieve sizes (mm)	% Pass of each size of aggregate				% Pass of each size of aggregate				Retained weight on each fraction size				
	25-12 mm	12-6 mm	6-0 mm	filler	25-12 mm	12-6 mm	6-0 mm	Filler	25-12 mm	12-6 mm	6-0 mm	filler	total
25	100	100	100	100	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0	**0.0**
19	93.4	100	100	100	6.53	0.00	0.00	0.00	22.63	0.0	0.0	0.0	**22.63**
9.5	3.73	90.59	99.88	100	89.74	9.41	0.12	0.00	310.96	24.8	0.6	0.0	**336.35**
4.75	0.50	4.56	94.9	100	3.23	86.03	4.98	0.00	11.19	227.1	23.3	0.0	**261.61**
2.36	0.25	0.60	64.6	100	0.25	3.96	30.30	0.00	0.87	10.4	141.7	0.0	**152.97**
0.3	0.13	0.24	23.13	99.8	0.12	0.36	41.46	0.21	0.41	1.0	193.8	0.05	**195.26**
0.075	0.06	0.14	6.89	92.8	0.07	0.10	16.25	6.95	0.23	0.3	75.9	1.53	**77.97**
Pan	0.00	0.00	0.00	0.0	0.06	0.14	6.89	92.84	0.22	0.4	32.7	20.42	**53.21**
% composition	**31.5**	**24.0**	**42.5**	**2.0**	100	100	100	0.00	**346.5**	**264.0**	**467**	**22.00**	**1100**
									1100				**1100**

II. Proportioning of plastic and Bitumen

Sample aggregate weight= 1100 grams					
Optimum Bitumen % (A)	**Wt. of OBC Bitumen(gm) (B)**	**Plastic % (C)**	**Plastic wt.(gm) D=B*C**	**Bitumen % E= 100-C**	**Wt. of Bitumen(gm) F=B-D**
5	57.75	0	0	100	57.75
5	57.75	5	2.88	95	54.88
5	57.75	10	5.75	90	52
5	57.75	14.3	8.26	85.7	49.49
5	57.75	15	8.66	85	49.1
5	57.75	20	11.55	80	46.2

III. Maximum theoretical density calculation for dry Modified HMA

AASHTO : T- 209-99						
Plastic content		**5**	**10**	**14.3**	**15**	**20**
Mass of Sample in Air a (g)		1139.4	1149.2	1144.8	1144.0	1145.2
Mass of Container Filled With Water b (g)		4693.3	4693.3	4693.3	4693.3	4693.3
Mass of Container Filled With Water & Sample c (g)		5347.1	5349.6	5345	5342.0	5349.1
Maximum Specific Gravity		2.346	2.332	2.322	2.310	2.340
Average	**2.346**		**2.332**	**2.322**	**2.310**	**2.340**

IV. Marshall Mix design test results of Dry modified HMA

Plastic content		**5 %**				**10 %**			
Specimen no.		**1**	**2**	**3**		**1**	**2**	**3**	
OBC. %		**5.0**	**5.0**	**5.0**		**5.0**	**5.0**	**5.0**	
Bitumen content by Total mix. %		**4.75**	**4.75**	**4.75**		**4.5**	**4.5**	**4.5**	
Plastic Content by wt. Of Total mix. %		**0.25**	**0.25**	**0.25**		**0.5**	**0.5**	**0.5**	
Mass of Sample in air g	**A**	**1140.3**	**1151.0**	**1145.6**		**1139.3**	**1145.7**	**1141.5**	
Mas of Sample in SSD g	**B**	**1141.7**	**1152.7**	**1147.1**		**1140.9**	**1147.4**	**1144.7**	
Mass of Sample in water g	**c**	**617.8**	**626.7**	**620.0**		**613.8**	**616.3**	**618.1**	
Description	**Formula**	**Calculation**			**Ave.**	**Calculation**			**Ave.**
Volume Sample Cm^3	**D= b-c**	**523.9**	**526.0**	**527.1**	**525.6**	**527.1**	**531.1**	**526.6**	**528.26**
Bulk Specific Gravity, Gmb	**E=a/d**	**2.177**	**2.188**	**2.173**	**2.179**	**2.161**	**2.157**	**2.168**	**2.162**
Maximum Theoretical Density	**F**	**2.346**	**2.346**	**2.346**	**2.346**	**2.332**	**2.332**	**2.332**	**2.332**
Agg. Combined Bulk Spec. Gravity, Gsb	**G**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**
Void in Mix (Va) %	**H=(f-e)/f*100**	**7.24**	**6.74**	**7.37**	**7.24**	**7.29**	**7.48**	**7.03**	**7.27**
Void filled Mineral Agg. (VMA)	**I=100-(M*E)/G**	**17.84**	**17.40**	**17.96**	**17.73**	**18.41**	**18.57**	**18.17**	**18.38**
Void filled Asphalt (VFA) %	**J =(I-H)/I*100**	**59.43**	**61.26**	**58.95**	**59.88**	**60.38**	**59.74**	**61.33**	**60.48**
Corrected Stability KN		**18.19**	**19.62**	**19.01**	**18.94**	**20.03**	**19.83**	**18.80**	**19.55**
Flow, in mm		**2.30**	**2.40**	**2.60**	**2.43**	**2.70**	**2.30**	**2.30**	**2.43**

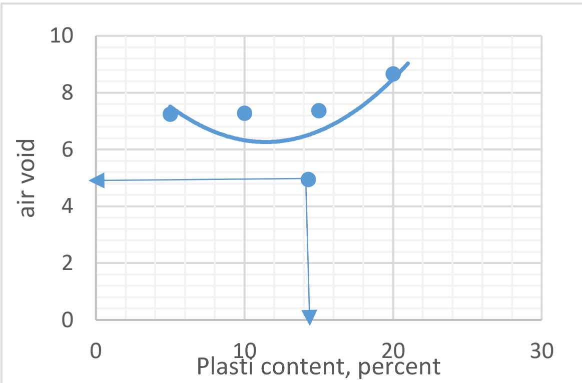
Plastic content		**14.3 %**				**15 %**			
Specimen no.		**1**	**2**	**3**		**1**	**2**	**3**	
OBC. %		**5.0**	**5.0**	**5.0**		**5.0**	**5.0**	**5.0**	
Bitumen content by Total mix. %		**4.285**	**4.285**	**4.285**		**4.25**	**4.25**	**4.25**	
Plastic Content by wt. Of Total mix. %		**0.715**	**0.715**	**0.715**		**0.75**	**0.75**	**0.75**	
Mass of Sample in air g	**A**	**1140.8**	**1147.3**	**1143.6**		**1142.8**	**1146.1**	**1141.9**	
Mas of Sample in SSD g	**B**	**1148.1**	**1149.6**	**1146.4**		**1146.3**	**1148.0**	**1143.6**	
Mass of Sample in water g	**C**	**608.8**	**616.1**	**613.6**		**613.2**	**618.0**	**611.3**	
Description	**Formula**	**Calculation**			**Ave.**	**Calculation**			**Ave.**
Volume Sample Cm^3	**D= b-c**	**539.3**	**533.5**	**532.8**	**535.2**	**533.1**	**530.0**	**532.3**	**531.8**
Bulk Specific Gravity, Gmb	**E=a/d**	**2.202**	**2.208**	**2.210**	**2.207**	**2.144**	**2.162**	**2.145**	**2.150**
Maximum Theoretical Density	**F**	**2.322**	**2.322**	**2.322**	**2.322**	**2.322**	**2.322**	**2.322**	**2.322**
Agg. Combined Bulk Spec. Gravity, Gsb	**G**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**
Void in Mix (Va) %	**H=(f-e)/f*100**	**5.16**	**4.88**	**4.79**	**4.94**	**7.66**	**6.86**	**7.60**	**7.37**
Void filled Mineral Agg. (VMA)	**I=100-(M*E)/G**	**16.88**	**16.64**	**16.56**	**16.69**	**19.08**	**18.37**	**19.02**	**18.82**
Void filled Asphalt (VFA) %	**J =(I-H)/I*100**	**69.45**	**70.66**	**71.07**	**71.07**	**59.83**	**62.68**	**60.05**	**60.85**
Corrected Stability KN		**19.21**	**24.12**	**20.44**	**21.26**	**19.21**	**24.93**	**20.44**	**21.53**
Flow, in mm		**2.50**	**2.35**	**2.20**	**2.35**	**2.30**	**2.40**	**2.20**	**2.30**

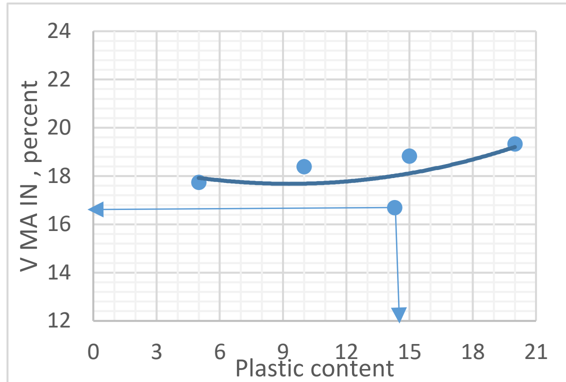
Plastic content		20 %			
Specimen no.		**1**	**2**	**3**	
OBC. %		**5.0**	**5.0**	**5.0**	
Bitumen content by Total mix. %		**4.0**	**4.0**	**4.0**	
Plastic Content by wt. Of Total mix. %		**1.0**	**1.0**	**1.0**	
Mass of Sample in air g	A	**1140.8**	**1147.3**	**1143.6**	
Mas of Sample in SSD g	B	**1148.1**	**1149.6**	**1146.4**	
Mass of Sample in water g	c	**608.8**	**616.1**	**613.6**	
Description	**Formula**	**Calculation**			**Ave.**
Volume Sample Cm^3	D= b-c	**539.3**	**533.5**	**532.8**	**535.2**
Bulk Specific Gravity, Gmb	E=a/d	**2.115**	**2.151**	**2.146**	**2.137**
Maximum Theoretical Density	F	**2.34**	**2.34**	**2.34**	**2.34**
Agg. Combined Bulk Spec. Gravity, Gsb	G	**2.517**	**2.517**	**2.517**	**2.517**
Void in Mix (Va) %	H=(f-e)/f*100	**9.60**	**8.10**	**8.27**	**8.66**
Void filled Mineral Agg. (VMA)	I=100-(M*E)/G	**20.15**	**18.82**	**18.98**	**19.32**
Void filled Asphalt (VFA) %	J =(I-H)/I*100	**52.348**	**56.97**	**56.40**	**55.24**
Corrected Stability KN		**21.87**	**22.07**	**21.87**	**21.94**
Flow, in mm		**2.20**	**2.25**	**2.30**	**2.25**

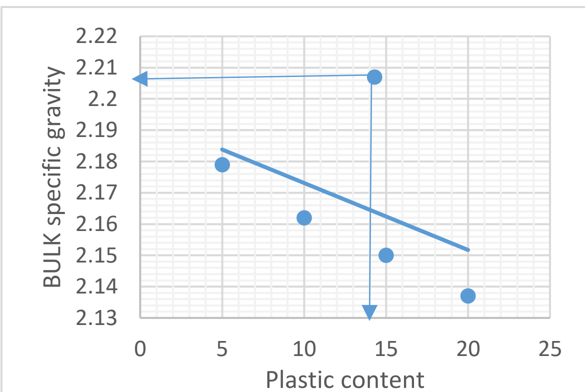
V. Dry modified Marshall Properties result at OPC

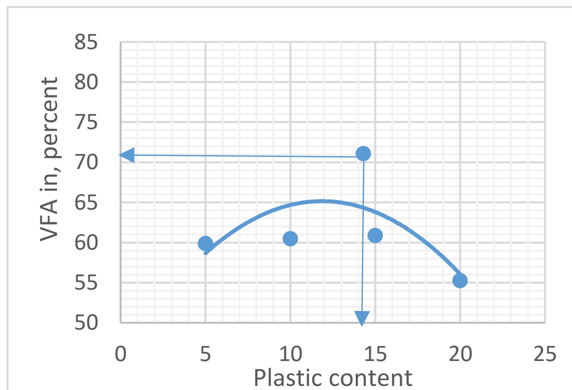
1	Bitumen Content	4.285 %
2	OPC	14.3 %
3	Stability	21.26
4	Flow	2.35
5	VA	4.94
6	VMA	16.69
7	VFA	71.07
8	Bulk specific gravity	2.207

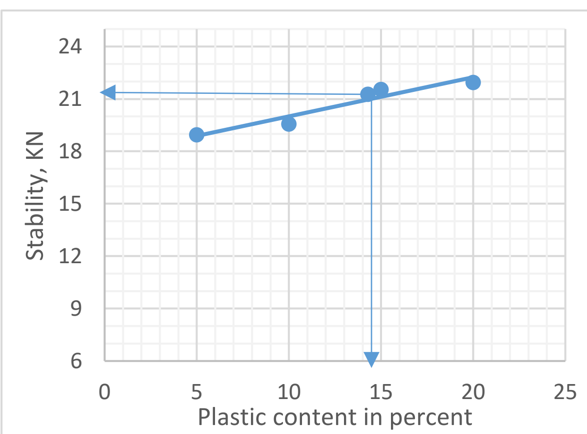
VI. Test property curve for dry modified HM

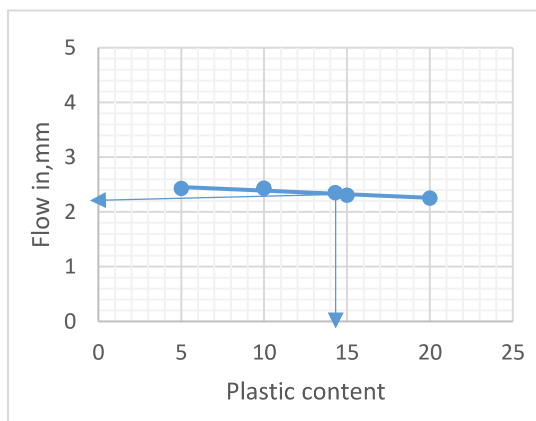












Appendix C: Wet modified Marshall Mix Design Results

I. Proportioning of plastic and Bitumen

Sample aggregate weight= 1100 grams					
Optimum Bitumen % (A)	**Wt. of OBC Bitumen(gm) (B)**	**Plastic % (C)**	**Plastic wt.(gm) D=B*C**	**Bitumen % E= 100-C**	**Wt. of Bitumen(gm) F=B-D**
5	57.75	0	0	100	57.75
5	57.75	2	1.16	98	56.59
5	57.75	4	2.31	96	55.44
5	57.75	6	3.46	94	54.29
5	57.75	8	4.62	92	53.13
5	57.75	10	5.77	90	51.98

II. Maximum theoretical density calculation for Wet Modified HMA

AASHTO : T- 209-99					
Plastic content	**2**	**4**	**6**	**8**	**10**
Mass of Sample in Air a (g)	1147.0	1149.4	1150.7	1142.0	1146.5
Mass of Container Filled With Water b (g)	4695.4	4695.4	4695.4	4695.4	4695.4
Mass of Container Filled With Water & Sample c (g)	5346.0	5352.3	5354.8	5355.0	5351.8
Maximum Specific Gravity	2.311	2.334	2.342	2.367	2.339
Average	**2.311**	**2.334**	**2.342**	**2.367**	**2.339**

III. Marshall Mix design test results of wet modified HMA

Plastic content		2%				4%			
Specimen no.		1	2	3		1	2	3	
OBC. %		5.0	5.0	5.0		5.0	5.0	5.0	
Bitumen content by Total mix. %		4.9	4.9	4.9		4.8	4.8	4.8	
Plastic Content by wt. Of Total mix. %		0.1	0.1	0.1		0.2	0.2	0.2	
Mass of Sample in air g	A	1143.9	1140.9	1150.6		1144.9	1152.1	1147.0	
Mas of Sample in SSD g	B	1146.1	1143.9	1153.8		1148.7	1155.7	1150.3	
Mass of Sample in water g	c	628.7	625.1	627.4		627.8	630.0	627.9	
Description	**Formula**	**Calculation**			**Ave.**	**Calculation**			**Ave.**
Volume Sample Cm^3	D= b-c	517.4	518.8	526.4	520.86	520.9	525.7	522.4	523
Bulk Specific Gravity, Gmb	E=a/d	2.211	2.199	2.186	2.199	2.198	2.192	2.196	2.195
Maximum Theoretical Density	F	2.311	2.311	2.311	2.311	2.334	2.334	2.334	2.334
Agg. Combined Bulk Spec. Gravity, Gsb	G	2.517	2.517	2.517	2.517	2.517	2.517	2.517	2.517
Void in Mix (Va) %	H=(f-e)/f*100	4.32	4.83	5.40	4.85	5.82	6.10	5.92	5.95
Void filled Mineral Agg. (VMA)	I=100-(M*E)/G	16.54	16.99	17.49	17.01	17.03	17.27	17.12	17.14
Void filled Asphalt (VFA) %	J =(I-H)/I*100	73.898	71.59	69.11	71.53	65.81	64.71	65.41	65.31
Corrected Stability KN		19.21	15.33	14.72	16.42	21.46	16.76	19.21	19.14
Flow, in mm		2.40	2.50	2.50	2.47	2.80	2.6	2.2	2.53

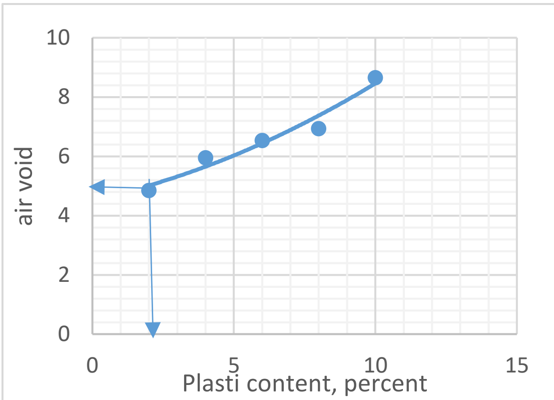
Plastic content		**6 %**				**8 %**			
Specimen no.		**1**	**2**	**3**		**1**	**2**	**3**	
OBC. %		**5.0**	**5.0**	**5.0**		**5.0**	**5.0**	**5.0**	
Bitumen content by Total mix. %		**4.7**	**4.7**	**4.7**		**4.6**	**4.6**	**4.6**	
Plastic Content by wt. Of Total mix. %		**0.3**	**0.3**	**0.3**		**0.4**	**0.4**	**0.4**	
Mass of Sample in air g	**A**	**1143.4**	**1142.5**	**1143.0**		**1138.3**	**1150.9**	**1144.6**	
Mas of Sample in SSD g	**B**	**1147.6**	**1145.1**	**1146.2**		**1141.5**	**1154.9**	**1150.3**	
Mass of Sample in water g	**c**	**625.1**	**623.1**	**624.2**		**624.8**	**630.1**	**628.5**	
Description	**Formula**	**Calculation**			**Ave.**	**Calculation**			**Ave.**
Volume Sample Cm^3	**D= b-c**	**522.5**	**522.0**	**522.0**	**522.16**	**516.7**	**524.8**	**521.9**	**521.03**
Bulk Specific Gravity, Gmb	**E=a/d**	**2.188**	**2.189**	**2.190**	**2.189**	**2.203**	**2.193**	**2.193**	**2.196**
Maximum Theoretical Density	**F**	**2.342**	**2.342**	**2.342**	**2.342**	**2.367**	**2.367**	**2.367**	**2.367**
Agg. Combined Bulk Spec. Gravity, Gsb	**G**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**	**2.517**
Void in Mix (Va) %	**H=(f-e)/f*100**	**6.57**	**6.55**	**6.52**	**6.54**	**6.94**	**7.36**	**7.35**	**6.94**
Void filled Mineral Agg. (VMA)	**I=100-(M*E)/G**	**17.39**	**17.38**	**17.35**	**17.37**	**16.84**	**17.22**	**17.20**	**17.09**
Void filled Asphalt (VFA) %	**J =(I-H)/I*100**	**62.24**	**62.30**	**62.44**	**62.33**	**58.78**	**57.23**	**57.28**	**57.77**
Corrected Stability KN		**17.99**	**16.96**	**17.50**	**17.48**	**15.53**	**15.33**	**19.83**	**16.90**
Flow, in mm		**2.9**	**2.6**	**2.8**	**2.77**	**2.50**	**2.60**	**2.55**	**2.55**

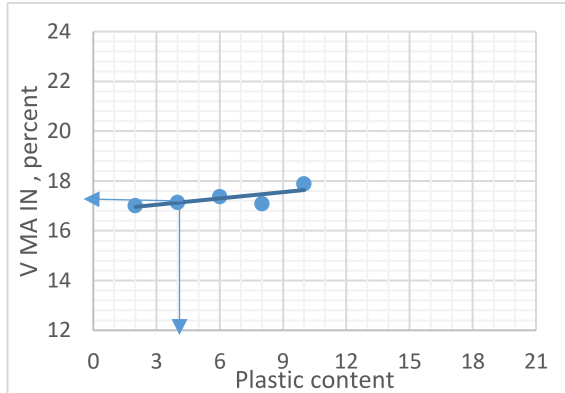
Plastic content		10 %			
Specimen no.		**1**	**2**	**3**	
OBC. %		**5.0**	**5.0**	**5.0**	
Bitumen content by Total mix. %		**4.0**	**4.0**	**4.0**	
Plastic Content by wt. Of Total mix. %		**1.0**	**1.0**	**1.0**	
Mass of Sample in air g	A	**1141.9**	**1146.9**	**1144.5**	
Mas of Sample in SSD g	B	**1145.1**	**1151.7**	**1148.3**	
Mass of Sample in water g	c	**620.8**	**623.3**	**622.8**	
Description	**Formula**	**Calculation**			**Ave.**
Volume Sample Cm^3	D= b-c	**524.3**	**528.4**	**525.5**	**526.06**
Bulk Specific Gravity, Gmb	E=a/d	**2.178**	**2.171**	**2.178**	**2.175**
Maximum Theoretical Density	F	**2.339**	**2.339**	**2.339**	**2.339**
Agg. Combined Bulk Spec. Gravity, Gsb	G	**2.517**	**2.517**	**2.517**	**2.517**
Void in Mix (Va) %	H=(f-e)/f*100	**6.90**	**7.22**	**6.90**	**7.00**
Void filled Mineral Agg. (VMA)	I=100-(M*E)/G	**17.79**	**18.07**	**17.79**	**17.88**
Void filled Asphalt (VFA) %	J =(I-H)/I*100	**61.215**	**60.06**	**61.21**	**60.83**
Corrected Stability KN		**16.15**	**16.15**	**15.74**	**16.01**
Flow, in mm		**2.40**	**2.40**	**2.50**	**2.43**

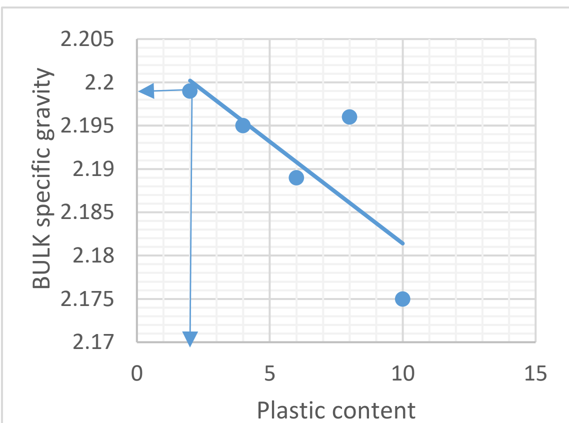
IV. Wet modified Marshall Properties result at OPC

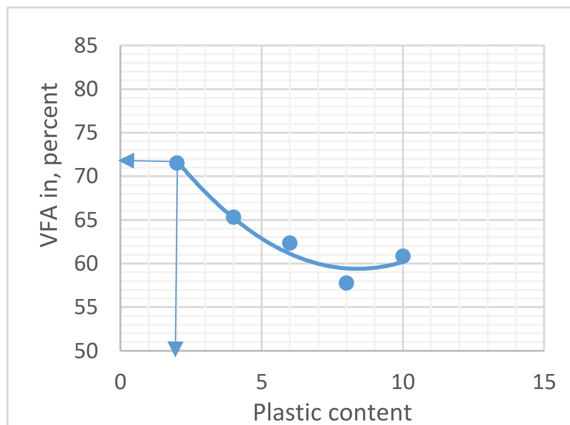
1	Bitumen Content	4.9
2	OPC	2 %
3	Stability	16.42
4	Flow	2.47
5	VA	4.85
6	VMA	17.01
7	VFA	71.53
8	Bulk specific gravity	2.199

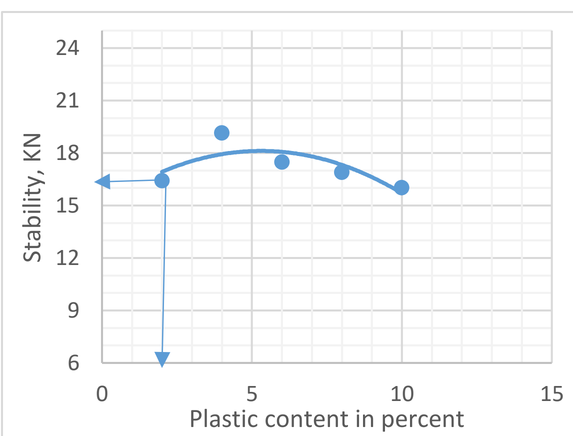
V. **Test property curve for Wet modified HM**

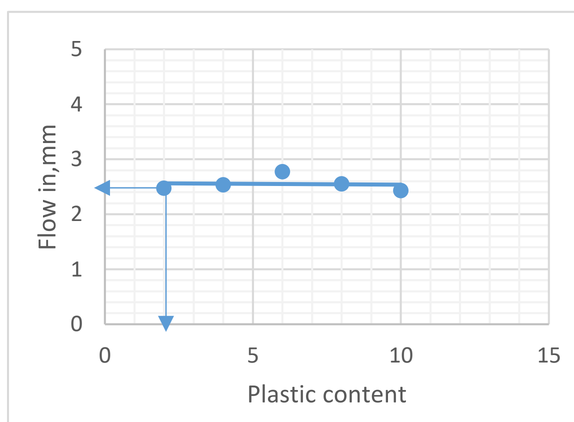












Appendix D: Dry and Wet Wheel tracking depth and wheel tracking rate determination

Cycles	Passes	Type of mix			
		Dry		Wet	
		Wheel tracking depth(mm)	Wheel tracking rate (mm/pass)	Wheel tracking depth(mm)	Wheel tracking rate (mm/pass)
1	2	0.04	0.0200000	0.01	0.005
250	500	0.27	0.0005400	0.37	0.00074
500	1000	0.33	0.0003300	0.5	0.0005
750	1500	0.4	0.0002667	0.58	0.000387
1000	2000	0.45	0.0002250	0.66	0.00033
1250	2500	0.47	0.0001880	0.74	0.000296
1500	3000	0.49	0.0001633	0.8	0.000267
1750	3500	0.52	0.0001486	0.83	0.000237
2000	4000	0.54	0.0001350	0.86	0.000215
2250	4500	0.56	0.0001244	0.93	0.000207
2500	5000	0.61	0.0001220	0.97	0.000194
2750	5500	0.65	0.0001182	1.02	0.000185
3000	6000	0.71	0.0001183	1.06	0.000177
3250	6500	0.78	0.0001200	1.13	0.000174
3500	7000	0.84	0.0001200	1.2	0.000171
3750	7500	0.87	0.0001160	1.28	0.000171
4000	8000	0.9	0.0001125	1.35	0.000169
4250	8500	0.94	0.0001106	1.43	0.000168
4500	9000	0.97	0.0001078	1.48	0.000164
4750	9500	0.99	0.0001042	1.54	0.000162
5000	10000	1.03	0.0001030	1.59	0.000159
5250	10500	1.06	0.0001010	1.64	0.000156
5500	11000	1.09	0.0000991	1.69	0.000154
5750	11500	1.11	0.0000965	1.74	0.000151
6000	12000	1.12	0.0000933	1.8	0.00015
6250	12500	1.14	0.0000912	1.84	0.000147
6500	13000	1.16	0.0000892	1.88	0.000145
6750	13500	1.17	0.0000867	1.93	0.000143
7000	14000	1.19	0.0000850	1.98	0.000141
7250	14500	1.2	0.0000828	12.02	0.000829
7500	15000	1.21	0.0000807	2.07	0.000138
7750	15500	1.22	0.0000787	2.1	0.000135
8000	16000	1.23	0.0000769	2.13	0.000133
8250	16500	1.24	0.0000752	2.19	0.000133
8500	17000	1.25	0.0000735	2.23	0.000131
8750	17500	1.26	0.0000720	2.27	0.00013
9000	18000	1.27	0.0000706	2.29	0.000127
9250	18500	1.28	0.0000692	2.31	0.000125
9500	19000	1.29	0.0000679	2.33	0.000123
9750	19500	1.3	0.0000667	2.37	0.000122
10000	20000	**1.31**	**0.0000655**	**2.39**	**0.00012**
Specification		$\leq 12mm$	$\leq 0.0005mm/Pass$	$\leq 12mm$	$\leq 0.0005mm/Pass$

Appendix E: indirect tensile strength and TSR result of Dry and wet modified HMA

I. Dry Modified indirect tensile strength and TSR result

Specimen condition	Specimen No.	specimen height (mm)	Diameter of the specimen	Maximum load applied (KN)	Ring factor	ITS	TSR
Dry	1	90	150	140	123.36	814.8	90.2 %
	2	90	150	155	123.36	901.7	
	3	90	150	130	123.36	756.3	
	Average ITS of dry Specimen					**824.3**	
Wet	1	90	150	150	123.36	872	
	2	90	150	120	123.36	698	
	3	90	150	115	123.36	669	
	Average ITS of wet specimen					**743.3**	

II. Wet Modified indirect tensile strength and TSR result

Specimen condition	Specimen No.	specimen height (mm)		Diameter of the specimen	Maximum load applied (KN)	Ring factor	ITS	TSR
Dry	1	90		150	197	123.36	1146	84 %
	2	90		150	180	123.36	1047.1	
	3	90		150	168	123.36	977.3	
		Average ITS of dry Specimen					**1056.8**	
Wet	1	90		150	163	123.36	948.21	
	2	90		150	144	123.36	837.69	
	3	90		150	151	123.36	878.41	
		Average ITS of wet specimen					**888.1**	

Appendix F: Optimization of dry and wet processes

$$X_{ij}= \begin{bmatrix} 21.26 & 2.207 & 16.69 & 1.31 & 0.000065 & 90.2 \\ 16.42 & 2.199 & 17.01 & 2.39 & 0.00012 & 84 \end{bmatrix}$$

$\sqrt{21.26^2+16.42^2}$=26.86 KN, $\sqrt{1.31^2+2.39^2}$ = 2.72 mm $\sqrt{2.207^2+2.199^2}$ =3.115 g/cm^3, $\sqrt{0.000065^2+0.00012^2}$ = 0.000136mm/pass, $\sqrt{16.69^2+17.01^2}$= 23.83 %, $\sqrt{90.2^2+84^2}$ =123.256%

Normalized decision Matrix (R_{ij}) =$\frac{21.26}{26.86}=0.79$, $\frac{16.42}{26.86}=0.611$,$\frac{2.207}{3.115}=0.71$, $\frac{2.199}{3.115}=0.7$, $\frac{16.69}{23.83}=0.7$, $\frac{17.01}{23.83}=0.71$, $\frac{1.31}{2.72}=0.48$, $\frac{0.000065}{0.000136}=0.477$, $\frac{0.00012}{0.000136}=0.88$, $\frac{90.2}{123.256}=0.73$, $\frac{84}{123.256}=0.681$

$$Rij= \begin{bmatrix} 0.79 & 0.71 & 0.7 & 0.48 & 0.477 & 0.73 \\ 0.611 & 0.7 & 0.7 & 0.87 & 0.88 & 0.68 \end{bmatrix}, V_{ij}= \begin{bmatrix} 0.16 & 0.071 & 0.07 & 0.096 & 0.095 & 0.15 \\ 0.12 & 0.07 & 0.071 & 0.17 & 0.18 & 0.14 \end{bmatrix}$$

A^+ = [0.16, 0.071, 0.071, 0.096, 0.095, 0.15], A^- = [0.12, 0.07, 0.7, 0.096, 0.095, 0.14].

For dry process, D^+ and D^- calculation is then,

$$D^+= \sqrt{(0.16-0.16)^2+(0.071-0.071)^2+(0.07-0.071)^2+(0.096-0.096)^2+(0.095-0.095)^{2+}+(0.15-0.15)^2}$$
$$=0.001$$

$$D^- =\sqrt{(0.16-0.12)^2+(0.071-0.070)^2+(0.07-0.070)^2+(0.096-0.096)^2+(0.095-0.095)^{2+}+(0.15-0.14)^2}$$

=0.0412, Closeness coefficient of Dry process is computed as the following,

$C_{dry}=\frac{0.0412}{(0.001+0.0412)}=0.97$, The same procedure also applied for wet process,

$$D^+= \sqrt{(0.12-0.16)^2+(0.07-0.071)^2+(0.071-0.071)^2+(0.17-0.096)^2+(0.18-0.095)^{2+}+(0.14-0.15)^2}$$
$$=0.12$$

$$D^- =\sqrt{(0.12-0.12)^2+(0.07-0.070)^2+(0.071-0.070)^2+(0.17-0.096)^2+(0.18-0.095)^{2+}+(0.14-0.14)^2}$$
$$=0.114$$

$C_{wet}=\frac{0.114}{(0.114+0.12)}=0.487.$ Hence C_{dry} is greater than C_{wet} therefore dry process is better than wet process based on TOPSIS principle.

Appendix G: Cost comparison between dry and wet processes

I. Conventional HMA Bitumen cost analysis.

- Volume of asphalt road section =(1000*7*0.05)m^3 =350 m^3
- Bulk specific gravity of conventional hot mix asphalt = 2238kg/m^3
- Total weight of hot mix asphalt = 350m^3*2238 kg/m^3 = 785,300 Kg
- Total weight of bitumen from the total mix asphalt =(5*783,300)/100=39,615 kg
- Number of drums needed for this road section =215.2
- 1 drum =182 kg
- Cost of 1 drum =30,000 ETB
- Cost of 1 kg bitumen =164.841 ETB
- Total cost of conventional HMA bitumen =164.841*39,165=6,456,000 birr
- Cost of waste plastic =60 birr/kg
- Processing cost of plastic=20 birr/kg
- Total cost of plastic =80 birr/kg
- OPC during dry process =14.3 % of bitumen
- OPC during wet process =2 %

II. Dry Mix bitumen cost analysis

Weight of bitumen replaced by plastic is 5600.6 kg, therefore total cost of binder in the dry process is calculated as;

(39615-5600.6)*164.841+ (5600.6*80) =5,979,461.1 ETB based on this the cost reduction is also computed as;

6,456,000- (33,564.405*164.841+5600.6*80) = 476,539 and % cos reduction is 7.831%

III. Wet mix bitumen cos analysis

Weight of bitumen replaced by plastic is 783.3 kg. Therefore total cost of binder in the wet process is calculated as;

(39165-783.3)*164.841+ (783.3*80) = 6,387,968 ETB and again cost reduction is also computed as;

6,456,000- (38,831.7*164.841+783.3*80) = 62,664 and % of cost reduction is 1.05 %.