JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HIGHWAY ENGINEERING STREAM

FINITE ELEMENT ANALYSIS OF POLYETHYLENE TEREPHTHALATE WASTE PLASTIC POLYMER AS A FILLER IN CRUMB RUBBER MODIFIED BINDER OF HOT MIX ASPHALT

A thesis submitted to the school of graduate studies, Jimma University, Jimma Institute of Technology, Faculty of Civil and Environmental Engineering in partial fulfilment of the requirement for the degree master of science in highway engineering

By
Getnet Mekuria Alemu

October, 2021
Jimma, Ethiopia

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Advisor: Dr. Damtew Tsige

Co-Advisor: Engr. Teyba Wedajo (PhD candidate)

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DECLARATION

I, hereby declare that the research work entitled "**Finite Element Analysis of Polyethylene Terephthalate Waste Plastic Polymer as a Filler in Crumb Rubber Modified Binder of Hot Mix Asphalt**" is a genuine record of an original research work done by me under the guidance of Dr. Damtew Tsige. In addition, Teyba Wedajo. (PhD. candidate). This research work was submitted in partial fulfilment of the requirements for the award of the degree of Master of Science in highway engineering. The entire work, or any part of it, has never been quantified for any other academic program. The content of the research was the result of work that has been carried out since the date of approval of the research program.

Mr. Getnet Mekuria	....	27 / 07 /2021 G.C
Name	Signature	Date

As research advisor, I hereby certify that I have read and evaluated this thesis paper. Prepared under my guidance, by Dr. Damtew Tsige. In addition, Teyba W. entitled "**Finite Element Analysis of Polyethylene Terephthalate Waste Plastic Polymer as a Filler in Crumb Rubber Modified Binder of Hot Mix Asphalt**" and recommended and would be accepted as a fulfilling requirement for the degree master of science in highway engineering.

Advisor: Dr. Damtew Tsige.	....	27 / 07 / 2021 G.C
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ABSTRACT

Ethiopia's highway network showed that a high percentage of roads are suffering from fatigue, creep, and rutting in the long term. These stresses may have occurred due to the shortage in the mechanistic properties of either of the increase in traffic load; these modifying properties of asphalt enhanced the mechanistic properties of hot mix asphalt. Nowadays, the use of recycled waste materials in road pavement is regarded not only as a positive option in terms of sustainability but also as an appealing option in terms of providing improved service performance. Therefore, the main aim of this research is to investigate the effects of crumb rubber and polyethylene terephthalate plastic polymer in asphalt mixture modification on the pavement responses using a finite element approach. The modification was performed both for asphalt binder and for asphalt mixture. The laboratory tests for asphalt mixture, such as a standard Marshall and Indirect tensile strength were conducted. In total, 69 samples were prepared: 15 as a control mix, which was prepared by blending course and fine selected with asphalt binder of 4, 4.5, 5, 5.5, and 6% of their weight to determine the optimum binder content, and the remaining to investigate the effects of adding different crumb rubber and polyethylene terephthalate plastic percentage to asphalt mix. Two proportions of crumb rubber (10% and 15%) by weight of asphalt binder were tested to modified asphalt binder, and four proportions of polyethylene terephthalate plastic (0, 2, 4, and 6%) by weight of crushed stone filler were used as partial replacement of filler content in the asphalt mix. The dimensional finite element model of Hot Mix Asphalt pavement structure was developed using Abaqus software to quantify the stress and deformation developed in the asphalt mixture due to static load. The asphalt binder test results showed that adding 10% crumb rubber as a modified reduced penetration by 1.56% and increased the softening point (by 4.33%) of the modified asphalt binder. The addition of 10% crumb rubber as asphalt binder modified and 2% of PET as partial replacement of crushed stone in the asphalt mixture was considered the best modifier that achieved maximum stability (increased by 0.17%), minimum flow (decrease by 20.07%), maximum stiffness (increased by 20.71%) and higher tensile strength of the asphalt mixtures. When crumb rubber and PET polymer are combined, vertical deformation is reduced by 23.65% and the percentage of stress is increased by 7.36%.

Keywords: *Asphalt mixture, Crumb rubber, PET, Finite element model, Marshall test*

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ABBREVIATIONS

AASHTO	America Association of State Highway and Transport Office
ASTM	America Society for Testing and Material
AV	Air Voids
BST	Bituminous Surface Treatment
CMA	Cold Mix Asphalt
CR	Crumb Rubber
ELT	End Life Tire
ETRMA	European Tire and Rubber Manufacturers Association
ERA	Ethiopian Road Authority
FE	Finite Element
FEM	Finite Element Modelling
HDPE	High Density Polyethylene
HMA	Hot Mix Asphalt
LDPE	Low Density Polyethylene
ITS	Indirect Tensile Strength
OBC	Optimum Binder Content
OGM	Open Graded Mix
PET	Polyethylene Terephthalate
PP	Polypropylene
PVC	Polyvinylchloride
S	Stress
SMA	Stone Matrix Asphalt
U2	Vertical Deformation
VFB	Voids Filled with Bitumen
VMA	Voids in Mineral Aggregate
WMA	Warm Mix Asphalt

CHAPTER ONE

INTRODUCTION

1.1 Background

Flexible pavements have a bitumen coating on top and a built-in layer and it is ensured that under application of load none of the layers is overstressed. The maximum intensity of stress occurred at the top layers. Hence, they are made from superior materials, mainly asphalt mixture [1]. Asphalt mixture is a heterogeneous material composed of asphalt binder, aggregates, and air voids. Approximately 85% of the total volume of the mix is the aggregates, asphalt binder constitutes around 10% of the total volume and the rest is air voids [2].

Due to extensively varying climatic conditions, construction materials, terrains, traffic volumes, and loading, the asphalt binder and asphalt mixture layer cannot withstand rutting, fatigue cracking, deformation potholing, wear and tear problems. Therefore, the asphalt binder and asphalt mixture need to be improved to meet the requirement of flexible pavement by adding a blend of polymer additives. Polymer implication for improving the properties of bitumen in a road pavement has been used more excessively. In this way, the road life span and consequently operation life have been significantly increased [3]. In short, a common method to improve the quality of asphalt binder and asphalt mixture is by modifying the rheological properties of asphalt binder and the asphalt mix by blending them with an organic synthetic polymer like rubber and plastic. They can return to the earth as beneficial additives in bitumen roads.

Plastic is the most commonly used material in the world today [4]. They come in five major categories, Polyethylene terephthalate (PET), High-density polyethylene(HDPE), Polyethylene (PE), polyvinylchloride (PVC), the polypropylene (PP), Low-density polyethene(LDPE) [5]. Among those plastics, Polyethylene Terephthalate (PET), which is mainly used for packaging drinks, makes plastic bottles, rigid food packaging, cleaners, oil, etc., [6], is the most wasted. In the US alone, 2675 tons of PET has been wasted in 2010, from which only 29.1% were recycled and the rest was disposed. [7]. In Ethiopia, a country cluster of EUROMAP-European plastic and rubber machinery put the per-capita plastic consumption in 2018 at 2.8kg, a 267% rise from a figure that puts the consumption per capita at 0.6kg in 2007. That places Ethiopia as the second-largest importer of plastic raw materials in central and eastern Africa and the fastest industry on the continent. Figure 1.1 shows the per capita consumption of plastic in Ethiopia has grown by about 13.1% annually over the past years. From 2.8kg in 2018 and is estimated to be 3.8kg in 2022.

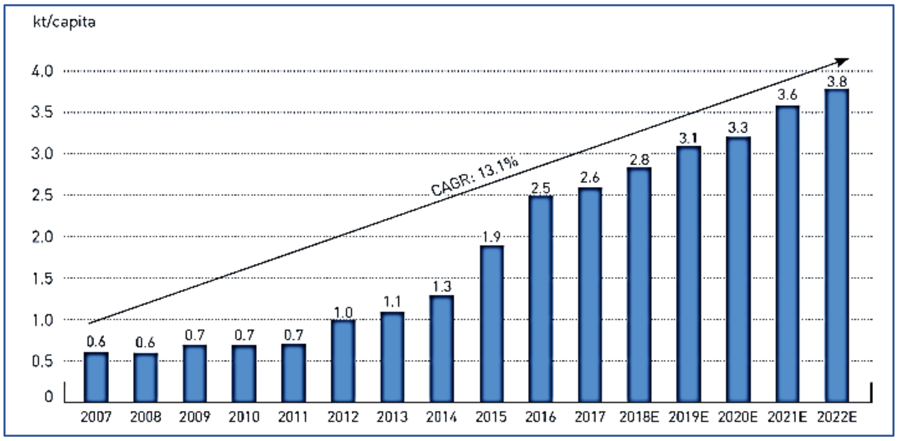


Figure 1.1 Per Capita Consumption of Plastic in Ethiopia (source: EUROMAP)

According to the annual report of the European Tire and Rubber Manufacturers Association (ETRMA), it was estimated that in 2013, the European Union produced 3.6 million tons of end-of-life tires (ELTs) [8]. According to statistics, millions of tires are annually collected and stored as waste after being discarded, creating many environmental problems and a lack of space required for storage. CR is a source from end-of-life tires (ELT) and has been used in asphalt mixtures since the 19th century [9]. The demand for cars is increasing in Ethiopia, particularly in the capital city Addis Ababa, as a result of urbanization. As the demand for automobiles grows, so does the demand for tires, resulting in an increase in tire waste. Tire debris is just discarded in the city with no regard for the environment, and there are only a few recycling alternatives available in the country, including reuse, open-air burning, material recycling, and rethreading. [10].

The calculation of displacements, stresses, and strains caused by vehicle loads in pavements is a difficult task even when considering all layers formed by linear elastic materials [11]. In reality, surface and granular layers present a complex constitutive behavior, with nonlinear and time-dependent effects. Such effects should be considered in mechanistic pavement design methodologies, which make use of the pavement structural response into specific distress models. Today, there is a trend in the pavement academic community to substitute pavement analysis based on the Multilayer Elastic Theory by analysis based on the Finite Element Method [12]. Therefore, the aim of this research work is to analyze pavement response due to utilization waste material especially waste crumb rubber and PET for asphalt mixture modification.

1.2 Statement of the Problem

Nowadays, in Ethiopia, traffic volume, loads, and tire pressure have increased substantially, which can cause increased rutting and cracking. In addition to traffic volume the percentage and type of filler in the asphalt mixture can reduce the durability of pavement material [13].

Old waste tires contain heavy metals and chemicals, which leach into the environment as these tires, disintegrate. A few of these chemicals have been recognized to be mutagenic and carcinogenic [14]. The soil around such old tires can easily be contaminated with harmful chemicals released into the environment. Even groundwater is at risk of becoming contaminated. Especially in Ethiopia, one of the main concerns in the case of discarded tires is an increased fire risk. Nearly half of the recycled scrap tires are used in fuel generation [15]. Beside this a plastic bottle require a huge amount of fossil fuels to both make and transport them. Of the mass number of plastic bottles consumed in Ethiopia, most of them are not recycled. Either they end up lying stagnant in landfills, leaching dangerous chemicals into the ground or they infiltrate our streets as litter as shown in the Figure 1.2 (a). They are found on the sidewalk, in the park, in front yards and rivers, and even if you chop them into tiny pieces, they still take more than a human lifetime to decompose [16].

Another problem related to pavement response is, the laboratory testing cannot simulate the conditions in the real road adequately and so the equations that predict the response of the materials to the stress and vertical deformation are also inaccurate. For example, one serious problem is that the properties of the materials change over the course of time and laboratory experiments cannot deal with this. Therefore it is better to use mechanistic empirical method like finite element model to know the effect of tire pressure on the response of pavement material [17].

a. Waste PET

b. Waste crumb rubber

Figure 1.2 Waste Polymers (photo credit: Getnet M.)

1.3 Research Question

1. What are engineering properties of asphalt mixture materials?
2. What is the effect of crumb rubber and PET on Marshall properties of modified asphalt mixture?
3. What is the optimum percentage of crumb rubber and PET in the asphalt mixture?
4. How crumb rubber and PET improves the deformation characteristics of asphalt mixture?

1.4 Objective

1.4.1 General Objective

The main objective of this study is to investigate the effects of crumb rubber and polyethylene terephthalate waste plastic polymer in asphalt mixture modification based on finite element analysis.

1.4.2 Specific Objective

- ❖ To determine the engineering properties of asphalt mixture materials.
- ❖ To study the Marshall properties of the modified asphalt mixture with crumb rubber and PET plastic polymer.
- ❖ To determine the optimum percentage of crumb rubber and PET in the asphalt mixture.
- ❖ To study stress and deformation characteristics of modified and mixture with neat bitumen.

1.5 Scope of the Study

The research involved study the performance of modified asphalt mixtures using waste materials identified. The study focused on flexible pavement of surface layer and the modifiers are crumb rubber and PET. Crumb rubber as asphalt binder modifier and PET as a filler. The percentage of CR was 10% and 15% by weight of asphalt binder and the percentage of PET was within the range of 0 – 6% with 2% incremental by weight of crushed stone filler. The finite element analysis target on stress and vertical deformation of asphalt mixture.

1.6 Significance of the Study

Finding useful application for waste vehicle tire and PET plastic as a part of solution for environmental problems resulting from disposal. In addition, study the ability of using crumb rubber and PET as asphalt mixture modifier in order to improve performance of mechanical properties of asphalt mixture as well as to extend their service life.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Flexible pavement is a surface constructed of bituminous materials. These can be either in the form of pavement surface treatment such as bituminous surface treatment (BST) generally found on lower volume roads and HMA, which is generally, used on higher volume roads or highway networks. Successful HMA pavement requires good planning, design, construction, and planned future maintenance. Asphalt pavements constructed of one or more courses of HMA are placed directly on the subbase or an aggregate base [18].

Flexible pavements are intended to limit the stress created at the subgrade level by the traffic traveling on the pavement surface so that the subgrade is not subject to significant deformations [17]. At the subgrade level, the concentrated loads of the vehicle wheels spread over a sufficiently large area. At the same time, the pavement materials themselves should not deteriorate to such an extent as to affect the riding quality and functionality of the pavement. Pavements do deteriorate due to time, climate, and traffic. As a result, limiting pavement deterioration that affects riding quality due to cracking, rutting, potholes, and other forms of surface distress to acceptable levels is critical [19].

2.2 Flexible Pavement Structure

A flexible pavement structure is generally composed of several layers of materials to accommodate this "flexing" effect. The purpose of pavement is to support loads, and flexible pavement uses a more flexible surface course to distribute loads over a smaller contributing area. It relies on a combination of layers for transmitting load to the subgrade flexible pavement and generally requires some sort of maintenance or rehabilitation every 10 to 15 years [20].

To take maximum advantage of this property, material layers are usually arranged in order of descending load-bearing capacity with the highest load-bearing capacity material (and most expensive) on the top and the lowest load-bearing capacity material (and least expensive) on the bottom [21].

2.2.1 Basic Structure Elements

Within a pavement structure, materials layers are typically arranged in order of decreasing load-bearing capacity. As shown in Figure 2.1, the pavement structure composed of three layers: surface course, base course and subbase [22].

The surface course should have high stiffness to be able to resist permanent deformation. On the other hand, the mixtures should have enough tensile stress at the bottom of the asphalt layer to resist fatigue cracking after many loads. Surface courses play an important role in characteristics of friction, smoothness, noise control, rut and shoving resistance, and drainage. Furthermore, the surface course serves to prevent the entrance of excessive quantities of surface water into the underlying base, subbase, and subgrade [9].

The base course is immediately beneath the surface course. It provides additional load distribution and contributes to drainage and frost resistance. Different base course materials may have different thicknesses. The subbase course layer is part of the flexible pavement structure consists of granular material, gravel, crushed stone, reclaimed material, or a combination of these materials [23]. It functions primarily as structural support but it can also: Minimize the intrusion of fine from the subgrade into the pavement structure, minimize frost action damage and provide a working platform for construction [24].

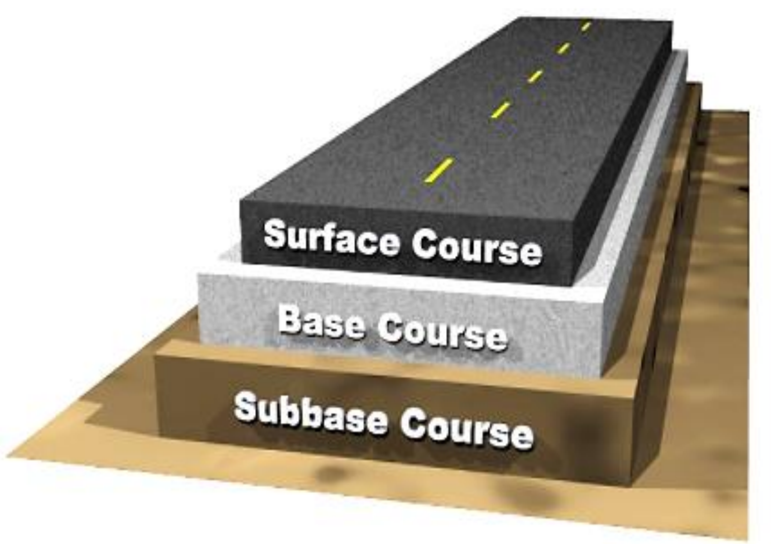


Figure 2.1 Flexible pavement structure (source: HMA Pavement Mix Type Selection Guide).

2.3 Asphalt Mixture

Asphalt mixture is a composite material consisting of material aggregate, asphalt binder, and air voids. It is produced at high temperatures by mixing a predetermined ratio of aggregate (coarse and fine), filler and, bitumen after the paving and compaction process to form a flexible pavement [17].

To be able to provide the best performance for different applications, a large variety of asphalt mixes be used. Due to the different requirements (amount of traffic, number of heavy vehicles, temperature, weather conditions, noise reduction requirements, etc.), the respective mix used needs to have sufficient stiffness and resistance to deformation to cope with the applied pressure. From vehicle wheels on the one hand, yet on the other hand, they need to have an adequate flexural strength to resist cracking caused by the varying pressure exerted on them. Moreover, good workability during application is essential to ensure that they can be fully compacted to achieve optimum durability.

2.3.1 Types of Asphalt Mixture

Warm Mix Asphalt (WMA): A typical WMA is produced at a temperature around 20 – 40 °C lower than an equivalent Hot Mix Asphalt. Significantly, less energy is involved and, consequently, fewer fumes are produced (as a rule of thumb, a reduction of 25 °C produces a reduction of 75% of fume emission). In addition, during the paving operations, the temperature of the material is lower, resulting in improved working conditions for the crew and an earlier opening of the road. Hot Mix Asphalt (HMA): Hot Asphalt Mixes are generally produced at a temperature between 150 and 180 °C. Depending on the usage, a different asphalt mixture [25]. Cold Mix Asphalt (CMA): Cold mixes are produced without heating the aggregate. This is only possible due to the use of bitumen emulsified in water, which breaks either during compaction or during mixing. Producing the coating of the aggregate. Over the curing time, water evaporates and strength increases. Cold mixes are especially suitable for low-traffic roads [17].

2.3.2 Hot Mix Asphalt

Hot-mix asphalt (HMA) is the most widely used paving material in the world. It known by many different names: HMA, asphaltic concrete, plant mix, bituminous mix, bituminous concrete, and many others. It is a combination of two primary ingredients, aggregate and asphalt binder. Aggregate includes both coarse and fine materials, typically a combination of different sizes of rock and sand. The aggregate total approximates 95% of the total mixture by weight. They mixed with approximately 5% asphalt binder to produce HMA. By volume, a typical HMA mixture is about 85% aggregate, 10% asphalt binder, and 5% air voids. It is the designation given to asphalt mixture that is heated and pours at a temperature between 300 and 350-degree Fahrenheit [19].

2.3.3 Materials for Hot Mix Asphalt

It is essential that the properties of the component materials of HMA meet minimum standards to ensure the material has satisfactory performance.

Aggregate is the most important component of HMA, and the quality and physical properties of these materials have a significant impact on mix performance. The qualities required of aggregate are described in terms of shape, hardness, durability, cleanliness, bitumen affinity, and porosity. In addition to these properties, the micro-texture of the aggregate particles will also strongly influence the performance of a compacted HMA layer. Smooth-surfaced River gravel, even partly crushed, may not generate as much internal friction as a crushed aggregate from particles having a coarse micro-texture. The coarse aggregate used for making HMA should be produced by crushing sound, un-weathered rock, or natural gravel. Gravel should be crush to produce at least two fractured faces on each particle. Filler (material finer than 0.075 mm) can be crushed rock fine, Portland cement, or hydrated lime [19].

Asphalt Binder: After refining crude oil, a thick, heavy residue of asphalt binder (bitumen) that holds aggregate together in HMA remains. Asphalt binder consists mostly of carbon and hydrogen, with small amounts of oxygen, Sulphur, and several metals. The physical properties of asphalt binder vary considerably with temperature. At high temperatures, asphalt binder is a fluid with a low consistency similar to that of oil. At room temperature, most asphalt binders will have the consistency of soft rubber. At sub-zero temperatures, asphalt binder can become very brittle [19].

2.3.4 Hot Mix Asphalt in Flexible Pavement

There are common types of HMA mix types used in flexible pavement those are dense-graded mixes (HMA), stone Matrix Asphalt (SMA) mixes, and open-graded mixes (OGM).

Stone Matrix Asphalt (SMA) Mixes: Stone matrix asphalt (SMA) has been used as a surface course to support heavy traffic loads and resist studded tire wear. As shown in the Figure 2.2 SMA is a gap-graded HMA developed to maximum rutting resistance and durability. Since aggregate does not deform as much as asphalt binder under load does, this stone-on-stone contact greatly reduces rutting. SMA benefits include weather friction due to a coarser surface texture, lower tire noise due to coarser surface texture, and less severe reflective cracking [26].

Dense Graded Mixes**:** A dense-graded mix is a well-graded HMA mixture intended for general use. When properly design and constructed, a dense-graded mix is relatively impermeable. Dense graded mixes are generally referred to by their nominal maximum aggregate size as shown in the Figure 2.2. The purpose of dense-graded mixes is suitable for all pavement layers and all traffic conditions. They work well for structural, friction, levelling, and patching needs [27].

Open-graded mixes (HMA): Previously, dense-graded and SMA mixes were usually not permeable. Therefore, an open-graded HMA mixture is designed to be water permeable. Open-graded mixes use only crushed stone or gravel and a small percentage of manufactured sands [26].

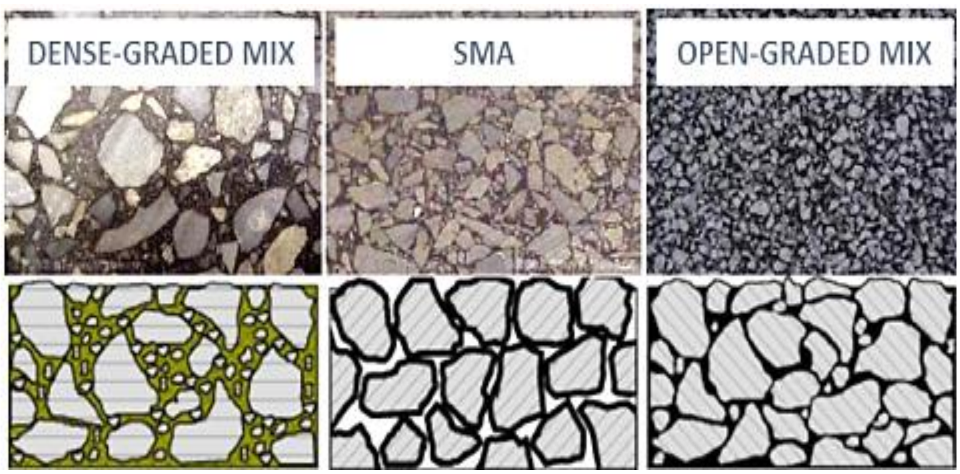


Figure 2.2 Types of HMA pavement mix type [27]

2.4 Pavement Failure

Pavement failure occurs as soon as the pavement surface no longer holds its original shape and develops material stress. When the pavement reaches its terminal life, the pavement surface suffers from distress, which is unable to provide a smooth surface for users. Categorically, pavement failure includes cracking potholes, depressions, rutting, shoving, upheavals, and ravelling. Several factors like causes that water intrusion, stress from heavy vehicle load enlargement and shrinking from seasonal temperature change, and sun exposure.

2.4.1 Types of Pavement Failure

Types of pavement distress are indications of the cause of the pavement failure. It has been noted in the research paper [28] that pavement distress (like ruts, potholes, raveling/freights, cracks) exhibited on the road surface are related to possible causes. There are many types of failure, that can reduce the quality of and performance of road pavement. These failures can be grouped into three main types. i.e., unevenness index, pavement cracking, and rutting are considered while other distress has been omitted while going for maintenance operations.

According to [29] pavement failure can be classified as structural, functional, or material failure or a combination of these factors. Structural failure is the loss of load-carrying capability, where the pavement is no longer able to absorb and transmit the wheel loading through the structure of the road without causing further deterioration. Functional failure is a broader term, which may indicate the loss of any function of the pavement such as skid resistance, structural capacity, and serviceability or passenger comfort. Materials failure occurs due to the disintegration or loss of materials characteristics of any of the component materials.

Asper[30], categorized the main types of pavement failure as either deformation failure or surface texture failures. Deformation failures include corrugation, depressions, and potholes, rutting, and shoving. These failures may be due to either traffic (load associated) or environmental (no-load associated) influences. It may also reflect serious underlying structural or material problems that may lead to cracking. Bleeding, cracking, polishing, stripping, and reveling are examples of surface texture failure. These failures indicated that while the road pavement may still be structurally sound, the surface no longer performs the function it is designed to do, which is normally to provide skid resistance, a smooth-running surface, and water tightness.

The cracking consists of visible discontinuities in the surface and can be an indication of the structural condition and severity of the pavement. The main problem with cracks is that they allow moisture into the pavement, giving accelerated deterioration of the pavement. Cracks can occur in a wide variety of patterns. They may result from a large number of causes, but generally are the result of either aging and embrittlement of surfacing, environmental conditions, structural or fatigue failure of the pavement, or any other causes [31]. The formation of cracks in the pavement surface causes numerous problems such as discomfort to the uses, reduction of safety, etc.

Fatigue cracking is related to traffic and is caused by excessive vertical compression and horizontal tensile strain at the top subgrade and the bottom of the asphalt layer due to repeated traffic loading. In addition to the above, intrusion of water causing reduction of the strength in lower layers as well as lowering of bearing capacity of subgrade soil by pumping of soil particles through the cracks is also a major problem associated with the pavements. This leads to the progressive degradation of the road pavement structure in the neighborhood of the cracks. The origin of cracks differs by their shapes, configuration, and amplitude of loading, movement of traffic, and rate of deformation [32].

Rutting is induced by traffic load and constitutes permanent deformation. Rutting deformation is caused by densification and shear deformation of the subgrade. According to M. Zumrawi [29], rutting is the permanent downward deformation of the surfacing within wheel paths. It may result from the deformation of the surfacing, the pavement materials or the underlying subgrade, or a combination of these. It is important to determine which layer is rutting since this will influence the optimal maintenance strategy. The worst level of rutting is the higher variation in the transverse profile of the road surf ace. Because of this, ruts interfere with surface run-off patterns and increase the risk of wetting in the upper pavement layers. Rutting can also initiate aquaplaning, and hence harm safety.

According to Ahmed [33] potholes are an indication of structural surface failure and they result from the growth of a break in the surface, often as a result of severe alligator cracking. Once water enters pavement layers, the base and/or subgrade become wet and unstable, and the resultant degradation leads to the rapid growth of pothole area and depth.

Wang et al [34]. reported that if the potholes are numerous or frequent, it may indicate underlying problems such as inadequate pavement or aged surfacing requiring rehabilitation or replacement. Water entering pavement could cause by a cracked surface, high shoulders or pavement depression, ponding water on pavement, porous or open surface, or clogged side ditches.

2.4.2 Factors Affecting Pavement Failure

Varieties of factors contributing to pavement deterioration have been investigated by many researchers. Lack of proper consideration of traffic loading, climate issues, material quality, and drainage issues are the main causes of pavement failure due to poor design. On the other hand, lack of proper supervision of the construction, low-quality construction materials, poor workmanship are the main causes of pavement failure attributed due to construction. These problems range from minor to very serious and to complex ones. Moreover, they can be localized or affect major parts of the pavement layers of the road. Furthermore, poor highway facilities, no local standard of practice, poor laboratory and in-situ tests on materials, and weak local professional bodies in highway design, construction, and management will lead to pavement failures.

The traffic or load-carrying ability of asphalt pavement is a function of both the thickness of the stiffness of the pavement and its material [32]. The deterioration of paved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. The road surface frequently wears due to traffic, especially in the early stages of the road's life. However, the action of traffic continues to wear the surface texture and thus gradually reduce the high-speed skidding resistance [21].

According to E. Ketema [18] he observed that the movement of heavy loaded truck trailers, tippers, as well as loaded fuel tankers might have caused pavement failures on the west lane of the ring road.

According to N. Okigbo,[21] indicated that the defects that most often cause injuries to people and damage to vehicles include inadequate road shoulders, pavement surface that is uneven, improperly marked signs, malfunctioning stoplights, construction negligence, and municipal negligence.

Traffic volume and size (especially for overloading) contribute to road safety and conditions. M. Zumrawi emphasized that the deteriorating of the flexible pavement is caused by under traffic loads. This effect depends on the technology and materials used for road construction, but the biggest effect depends on traffic loads and volumes [29].

The two critical areas of the environment that cause pavement failure are temperature and water or rainfall. Temperature influences the choice of asphalt binder grade for use in asphalt pavement. Asphalt pavement is susceptible to damage by water. Water increases moisture in the pavement and reduces bearing capacity. It saturates the subgrade or base of asphalt pavement and causes structural damage to the pavement in climates that have extensive rainfall. Rainfall can alter moisture balances and influence pavement deterioration, whereas temperature changes can affect bitumen aging, resulting in embrittlement of the bitumen, which causes the surface to crack and, as a result, a loss of surface seal waterproofing [35].

The use of low-quality construction materials adversely affects the performance of the road. This sometimes occurs in the form of the improper grading of aggregate for base or subbase and poor sub-grading soil of low bearing strength. The use of marginal or substandard base materials for pavement construction will affect pavement performance [36]. These materials may accelerate deterioration of the pavement and often result in rutting, cracking, shoving, raveling, aggregate abrasion, low skid resistance, low strength, shortened service life, or some combination of these problems [34].

N. Okigbo investigated the causes of highway pavement failure along a road in south-western Nigeria. He stated that the materials used as subbase have geotechnical properties below the specification and this is likely to be responsible for the road failure. The base materials with high fine content are susceptible to loss of strength and load-supporting capability upon wetting [21].

The highway drainage system includes the water handling system, which includes pavement surface, shoulder drains, and culverts. These elements of the drainage system must be properly design, built, and maintain. When a road fails, inadequate drainage is often a major factor. Poor design can direct the water tank onto the road or keep it from draining away. When there is too much water on the surface, it can cause potholes, cracks, and pavement failure. [29] suggested that water plays a primary role in reducing the service life of a pavement or embankment and increasing the need for rehabilitation measures. The cracks allow moisture to enter the pavement, allowing accelerated pavement degradation and this is the main problem. This leads to the gradual deterioration of the pavement structure in the neighborhood of the cracks.

The ultimate durability of an asphalt mixture and pavement structure is directly dependent on the quality of the workmanship used to construct the project. The best set of specifications, if not followed, will not assure a good, long-lasting pavement. One of the more significant causes of asphalt's premature deterioration is poor workmanship. Many times, poor workmanship involves ignorance of a specification, proper construction techniques, or proper operation of equipment.

Some basic requirements of a pavement; it should be structurally sound enough to withstand the pressure on it. The thickness of the pavement should be sufficient to distribute the stress and load to safe value on the subgrade soil [37]. The performance of the asphalt mixture can be improved with the utilization of various types of additives. These additives include polymers, latex, fibers, and many chemical additives. Because the use of additives plays an important role in improving the properties of asphalt mixture, many studies continue to look for new additions to improve the properties of asphalt mixture [38].

2.5 Enhancing Asphalt Pavement Performance using Asphalt Additives

The factors affecting asphalt pavement durability can be grouped into material properties (e.g., aggregate particle size distribution, binder grade, binder content, and air void content), loading specificity (e.g., magnitude of load, contact area, and tire pressure), and climatic conditions (e.g., moisture and temperature). The proper incorporation of these factors into the asphalt mixture design ensures desirable asphalt pavement performance [39].

Fatigue cracking, rutting, and other cracking of asphalt pavement caused by repeated traffic loading at intermediate temperatures is primary distress during the in-service period, which is an important factor in determining the durability of asphalt pavement [34]. The fatigue performance of asphalt mixture is strongly related to the viscoelastic binder that determines the rheological, cohesive, and adhesive behaviors of asphalt mixtures at different material scales. Binders with good fatigue performance are beneficial for improving the fatigue resistance of asphalt mixtures. Therefore, CRMB with plastic mix additives is of great importance to optimize the mix design and to extend the service life of pavements with warm mixed rubberized asphalt mixtures [34].

Researchers have investigated the benefits of using waste materials in the construction industry to better manage waste and to enhance the quality of construction materials [40]. Currently, several waste materials, such as waste glass, plastic, tires, etc., are used to improve the construction of various pavement layers, including the asphalt surface [41]. Asphalt pavements will be exposed to deterioration after construction, due to traffic loading activity and climatic conditions. This process can be delay if good materials are used in the construction phase. Usually, materials that used as a modifier of asphalt binder have better performance than conventional ones [42].

According to [43], asphalt binder modification provides several benefits such as a sufficient increase in the consistency of the asphalt pavement to prevent plastic deformation at high temperatures; Enhanced asphalt binder elasticity and flexibility to avoid loss due to chipping or cracking at low temperature; Increased adhesion between asphalt binder and aggregate; improved aging resistance and homogeneity, and high thermal stability, which helps decrease the stiffening and initial aging of asphalt binders during mixing and road construction.

2.5.1 Use of Re-Cycled Crumb Rubber as Additives in Asphalt Mixture

N. S. Mashaan,and his friends, stated that rubber modified binder and mixture have revealed improvement in the properties such as rutting resistance, and fatigue, thermal and reflective cracking resistance[9].

According to [44] research, there are numerous advantages to using crumb rubber as a modifier. Such as increased pavement life, reduced traffic noise and maintenance costs, increased resistance to rutting and cracking, and so on., the addition of crumb rubber into asphalt binder can increase the viscosity, therefore, higher mixing and compaction temperatures may be required to meet the specifications.

The addition of crumb rubber to bitumen increases the modified bitumen viscosity, softening point and lower susceptibility to temperature variations, higher resistance to buckling at elevated pavement temperature [45]. This modified bitumen showed higher durability, better adhesion between aggregate and binder, presentation of cracking, reflective cracking, and overall improved performance in extreme climatic conditions under heavy traffic conditions [44].

Crumb rubber tires improved the resistance of asphalt pavement to rutting, fatigue cracking, and low temperature cracking, which enables it to perform better than conventional asphalt roads [9].

2.5.2 Use of Re-Cycled Plastic as Additives in Asphalt Mixture

The performance of the bituminous mixture used for surfacing in flexible pavements can be improved by incorporating suitable additives into the mixture [21]. These additives include commercial materials, by-products, and even processed waste materials. Re-cycled plastic, mainly polyethylene, can be used in the manufacture of polymer-modified asphalt cement or bitumen. Re-cycled polyethylene from grocery bags in bituminous pavements results in reduced rutting and low temperature cracking of the pavement surfacing [38].

The possible use of waste plastic for the improvement of bitumen characteristics. It was observed that the penetration and ductility values of the modified bitumen decreased with the increase in the portion of the plastic additives, up to 0.5% by weight. Therefore, the life of the pavement-surfacing course using the modified bitumen also expected to increase substantially in comparison to the use of ordinary bitumen [46].

O. M. Ogundipe investigates the potential use of polyethene as a modifier for asphalt paving materials and indicates that modified binders reduce pavement deformation; increase fatigue resistance and provide better adhesion between the asphalt and the aggregate. It was found to increase the stability, reduce the density and slightly increase the air voids and the voids of mineral aggregate[47].

A study on “Medical Plastic Waste Disposal by Using in Bituminous Road Construction” stated that while bitumen as a binder helps to improve the strength and life of road pavement, its water resistance is poor, whereas polymer modified bitumen has better resistance to temperature and water [40].

N. Rahman and his friends observed that the asphalt mixtures with waste polyethylene modifier up to 10% and waste PVC modifier up to 7.5% be used for flexible pavement construction in a warmer region from the standpoint of stability stiffen and void characteristics[48].

Incorporated shredded waste plastic into BC mixture directly with the hot aggregates. Out of the various plastic dosages tested, the plastic content (6% by weight of bitumen) yielded the best results [42].

J. De Arimateia and his friends, investigated the Marshall stability of polyethylene terephthalate (PET) modified bituminous mixes and sought to acquire the most desirable percentage of PET for modification of the bitumen. The result indicated that the addition of PET significantly enhanced the performance characteristic of the parent binder at 8% PET addition where Marshall Stability value increased by approximately 60% and the flow value increased by 40% compared to the unmodified sample [49].

The Marshall stability of fine PET-particle mixtures is higher than the Marshall stability of coarse PET particle mixtures. Fine PET particles can be evenly distributed throughout the mixture, filling gaps and stiffening the binder. Furthermore, visual examination of PET particles revealed that coarse particles are not flat and have a curly shape, increasing voids in the mixture and a decrease in stability.

E. Ahmadinia, found that the mixture containing up to 5% of micronized PET has higher indirect tensile strength, resistance against moisture damage and fatigue cracking, and resilient modulus than the control mixture without PET. However, the flow number of mixtures found to be lower than that of the control mixture, indicating that the resistance against permanent deformation decreases with PET modification [50].

To overcome these drawbacks of commonly used modified technique and make a better asphalt mixture providing longer service life. The integrated bitumen modification method employed in this paper to produce modified bitumen and modified asphalt mixtures by using both thermoplastic elastomers and plastomer agents.

2.6 Background about Finite Element Modelling

Various empirical methods have been developed for analyzing flexible pavement structures. Due to the limitations of analytical techniques developed in the 1960s and 1970s, the design of flexible pavements is still largely based on the empirical method**.** Huang studied the disadvantage of the empirical method is the limitation of a certain set of environmental and material properties [51]. If the conditions change, the design is no longer valid. The new technique is the mechanistic-empirical method that can simulate the wheel load and determines the stress.

The mechanistic method is more effective for analyzing data than the empirical method. However, the effectiveness of any mechanistic design method depends on the accuracy of the expected stresses and strains. Due to their flexibility and power, Finite Element (FE) methods are increasingly being used to analyses flexible pavements. Flexible pavement can be simulated using FE by several methods, two-dimensional (2D) and three-dimensional (3D) FE methods [33].

3D FE modelling is widely viewed as the best approach to understanding pavement performance. A pavement system is typically modelled as a multi-layered structure with different material properties in each layer. It should mention that; 3D modelling is better than 2D modelling for generating more realistic results generally requires more intensive pre-processing procedures. Further, the number of parameters increases, and the total computational time and the amount of memory will increase tremendously [52].

ABAQUS is a common FE program. It has been used in the structural analysis of pavement systems. It can accommodate both 2D FE analysis and 3D FE analysis and use reduced integration elements 3D to reduce the total computational time. To investigate whether 3D FE analyses are necessary or even benefit in the routine design, differences between the results yielded by 3D analyses and those from 2D FE. It showed that ABAQUS tends to generate the lowest tensile strain in all cases and maximum deflections compared with those obtained from the 2D axis-symmetric program MICH-PAVE; ILLI-PAVE gave the lowest maximum surface deflection due to the fixed boundary at a certain depth [33].

According to A. M. Sawan study the modifying asphalt mixture using silica fume is considered the best modifier that achieves the greater total stress under the effect of the maximum traffic load it achieves 28% increase in total stress compared with the mixture with neat bitumen [52]. Using additives such as crumb rubber and PET would affect the engineering properties of the asphalt layer. A comparison between the obtained performance and that of modifications using the conventional mentioned additives is necessary. In addition, a 3-D finite element analysis is needed to investigate the effect of using the mentioned additives on the modified asphalt layer responses (vertical deformation and stress) and compare that with those of the conventional additives.

Exploring literature shows that the effects of adding waste PET as a filler in the crumb rubber modified asphalt mixture has not been conducted yet. Therefore, in this study, it was aimed to study the effect of adding both crumb rubber and PET on the mechanical properties of asphalt mixture using finite element approach.

Table 2.1 Summary of related work

Authors	Types of waste	Shape or size	Percentage of waste used	Governed % of waste
M. T. Awwad and L. Shbeeb [41]	Commercial HDPE and LDPE	Grinded and not grinded (2- 3 mm)	6%, 8%, 10%, 12%, 14%, 16% and 18%	12% HDPE increase Marshall stability
E. Ahmadinia [50]	Waste PET	Chips/ shredded 1.18 mm	2%, 4%, 6%, 8% and 10%	6% by weight of bitumen improving Marshall stability and resistance to permanent deformation.
D. Casey [53]	Waste PP, Waste HDPE, and Waste LDPE	Mulch PP, Powder HDPE, and LDPE	2%, 3%, 4% and 5%	4% HDPE improve binder rheological properties
Khan et al., [54]	Waste LDPE and HDPE	Powder 0.15- 0.75mm	2%, 4%, 8% and 10%	4% HDPE and 10% LDPE better rutting resistance
Ho et al.,[55]	Waste PE and LDPE	PE: Wax, LDPE: pellet and shredded	2% and 4%	4% LDPE with a lower molecular weight
X. Shu and B. Huang [56]	Crumb rubber	Fine Scrap tire	10%, 15% and 20%	Increase resistance to rutting, fatigue cracking, low-temperature cracking, storage instability, and phase separation. Need to modify operations to handle the mixture.
D. Lo Presti [14]	Review of recycled tire rubber (RTR)	Powder Scrap tire	2% up to 25%	Asphalt binder pavement is more cost-effective than conventional pavement. Recommended use of high viscosity RTR MBS in open-graded

				asphalt mixes and no agitation RTR MBs for long-term performance. Poor information, lack of training of personal and stakeholders, and poor local policy prevent the full actualize of RTR-MBs technology.
Junior et al., [57]	Scrap tire rubber	Fine Scrap tire	2%, 4%, 6%, 8% and 10%	Potential substitution of SBS with STR requires proper care during storage and transportation with a potential 10% expenditure saving. STR had an electric recovery of 55% >3% of ordinary asphalt.
Cong et al [58]	0.425 mm crushed rubber	0.425mm size	5%, 10% and 15%	The addition of CR increases SP, elastic recovery, viscosity, rutting resistance, and decrease penetration, ductility. However, CR- modified asphalt binder has poor storage stability and swelling properties. Recommended the use of soft asphalt with CR
Yu et al., [59]	Aged plastic plus Crumb rubber	Scrap tire	10%, 12%, 14%, 16% and 18%	PRA is more environmentally friendly in terms of energy consumption and GHHs. It exhibits comparable low and high-temperature performance and water susceptibility with SBS. SBS is superior in terms of softening point, elastic recovery, and fatigue performance.

CHAPTER THREE

MATERIALS AND METHODS

3.1 General

The main objective of this study is to investigate the effect of Crumb rubber and Polyethylene Terephthalate plastic polymer in asphalt mixtures modification related to the pavement responses using a finite element approach. To achieve this objective, a thoroughly experimental program was a design and implemented. The study design is shown in

Figure 3.2. It consists of three phases. The first phase is to evaluate used materials properties such as aggregate and bitumen, while the second phase is to describe how laboratory work or experimental work has been done to achieve the study objective. The third and final phase is an analysis of FE modelling.

3.2 Study Area

The study area of this research was held in Addis Ababa. Addis Ababa is the capital and largest city of Ethiopia. Addis Ababa lies at an elevation of 2,355 meters (7,726 ft.) and is a grassland biome, located at 8°53′31″N - 9°1′48″N latitude and 38°44′24″E - 38°47′29″E longitude. Addis Ababa has a subtropical highland climate with precipitation varying considerably by the month. The city has a complex mix of alpine climate zones, with temperature differences of up to 10 °C (18 °F), depending on elevation and prevailing wind patterns [60].

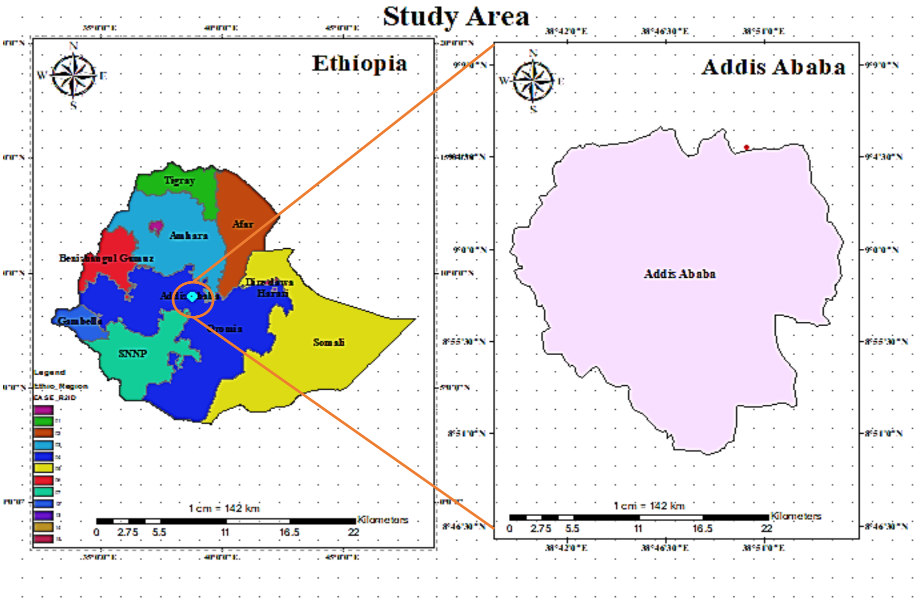


Figure 3.1 Study Area (Source: ArcGIS 10.3.1 Software)

3.3 Study Variables

3.3.1 Dependent Variable

- Optimum dosage of PET and crumb rubber.

3.3.2 Independent Variable

- Physical properties of modified bitumen.
- Marshal properties of mixture.
- Performance properties of mixture.
- Stress characteristics of mixture.
- Deformation characteristics of mixture.

3.4 Parameters

The parameters under study were the materials used to prepare the modified asphalt mixture like bitumen, aggregate, waste crumb rubber, and PET waste plastic and the finite element method for the analysis of the pavement structure. Therefore, this research has been conducted on the impacts of the above-listed parameter of their values for the results of the finding.

3.5 Research Design

The study used an Experimental and Finite Element method. Study design to answer the research question and achieve its objectives based on analytical and experimental findings through quantitative qualitative and comparative analysis approach. The experimental study was used to evaluate the properties of the modified asphalt mixture with crumb rubber and PET plastic waste as per ASTM, AASHTO, and ERA specifications. In addition, the Finite Element method was evaluating the stress and vertical deformation properties of the asphalt mixture.

The first step was to collect data on the materials used for mix design (aggregate, asphalt binder, crumb rubber, and PET), and then the physical quality of the materials was tested in the laboratory according to specifications. Subsequently, a trial Marshall Mixture design was performed based on different binder content to determine the optimum binder content of the conventional asphalt mixture. Applying 75 blows to each face following ASTMD1559, using five different binder contents (4%, 4.5%, 5%, 5.5%, and 6%) to create the standard Marshall specimen by weight of the total mix and single conventional filler content namely crashed stone dust (5.5%). After preparation of the HMA mix, Marshall Stability and flow value were determined using a test machine. Then the volumetric properties of the asphalt mixes were calculated. The Marshall design requirement criteria were checked by the design specification guideline. The optimum bitumen content (OBC) was obtained from the achieved results of the specimens.

Using the wet process method, the optimum binder content was modified by different percentages (10% and 15%) of crumb rubber by weight of OBC, and the physical quality features of the changed asphalt binder were studied to identify the optimum percentage of crumb rubber.

The modified asphalt mixture was made with a combination of modified asphalt binder (at the optimal proportion) and varying amounts of PET (by weight of filler material) in the mix (0%, 2%, 4%, and 6%). To find the optimum dosage of PET, the Marshall test was used, and the influence of those polymers on the mixture was investigated using moisture susceptibility tests. Finally, the experiment's results were analyzed using a finite element technique.

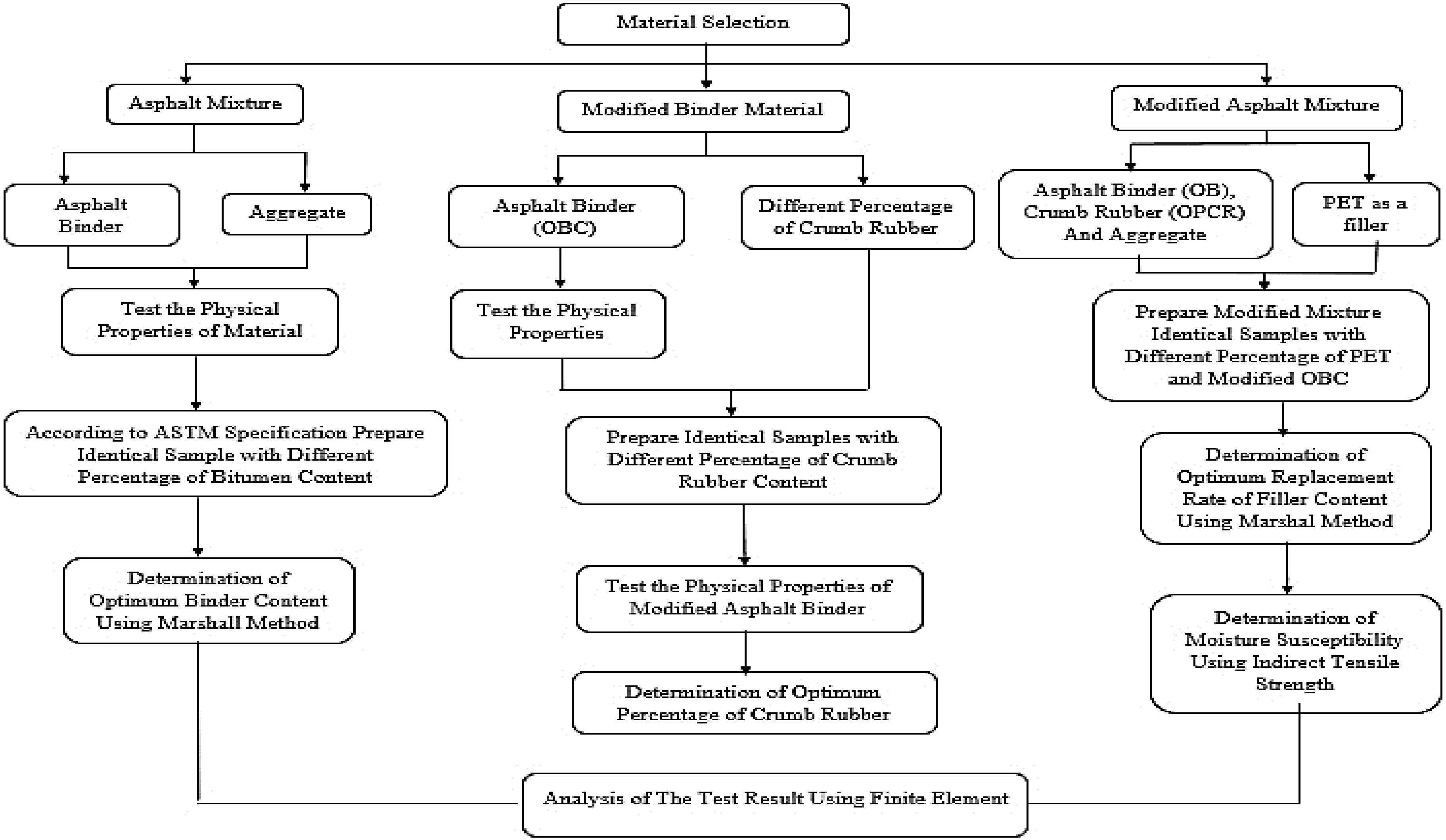


Figure 3.2 Study Design

3.6 Data Collection

Study data gathered from two sources: primary and secondary. Primary data was collected from experimental laboratory investigation, for instance, the physical property of bitumen, aggregate, Marshall Stability, and flow. In addition, primary data include crumb rubber and PET plastic polymer, which are waste polymers employed in the modified asphalt mixture. Secondary data was gathered from prior studies on the issue, a laboratory handbook, and several specifications such as ASTM, AASHTO, and ERA.

All materials were procured from **Acer Construction Company in Addis Ababa**, including asphalt binder of 80/100 penetration grade, coarse aggregate retained on a 4.75mm filter, fine aggregate retained on a 0.075mm screen, and stone dust filler. PET post-consumer plastic bottle debris was collected from a variety of garbage generating locations in **Addis Ababa's Akaki Kality Sub-city**, including cafeterias and halls of residence. Waste tires were also gathered from the environment.

3.7 Materials

Asphalt mixture is normally composed of bitumen and aggregate. Generally, aggregates divided into coarse, fine, and filler fractions according to the size of particles. The following section includes the description of four types of material including Bitumen, Aggregate, Crumb Rubber, and Waste ground PET used in the study.

3.7.1 Bitumen

Bitumen is a sticky, black and highly viscous liquid or semi- solid, in some natural deposits. It is also the residue or by product of fractional distillation of crude petroleum [61]. One type of conventional bitumen was select to prepare modified bitumen as shown in Figure 3.3 (a). The asphalt binder with a grade of 80/100 was used. It was sourced from hot mix plant located in Akaki Kality Sub-city Addis Ababa.

3.7.2 Aggregate

Aggregate constitutes the granular part in bituminous asphalt mixture that contribute a large percentage of the mixture weight and contributes to most of the load-bearing and strength characteristics of the mixture as shown in the Figure 3.3 (b). The physical properties of the aggregate used in the mixture depending on AASHTO and ASTM specifications. The aggregate used was strong, tough, durable, and can be crushed into bulky particles without many flaky particles. In addition to the graduation requirements, the aggregate is also requiring to possess the strength to carry and transmit the applied loads. **Coarse Aggregate:** The aggregate retained on sieve number 4.75mm is called coarse aggregate. The coarse aggregate was screened crushed rock, angular in shape, free from dust particles, clay, vegetation, and organic matters. **Fine aggregate**: The fine aggregate was clean-screened quarry dust. It was free from clay, loam, vegetation, or organic matter. The fine aggregate was having a size from 1mm up to 0.075mm. **Filler** in the mix fills up the voids left in the aggregates to increase the density and enhanced strength of the mixture. One of the criteria that will affect the suitability of a filler to be used is it is fineness. In this study a crushed stone that pass through 75µm IS sieve. The course, fine aggregate and filler used for this work was from Acer Construction Company located around Bole Michael in Addis Ababa.

a. Asphalt Binder b. Aggregate

Figure 3.3 Conventional Materials (photo credit by Getnet M)

3.7.3 Waste Materials

Polymers most often used in modifying bitumen can be grouped into two general categories such that elastomers and plastomer. Crumb rubber is categorized as elastomers, as the name suggests, elastomers can be stretched like a rubber band and recover their shape when the stretching force is released. Therefore, elastomers can resist permanent rutting better. On the other hand, polyethylene, which is categorized as a plastomer, forms tough. This plastomer gives high initial strength to the asphalt mixture to resist heavy loads.

Crumb Rubber

Crumb rubber is one of the additives for bitumen modification, which is derived from reclaimed passenger car tires available in Akaki Kality sub city. The crumb rubber was produced by reducing scrap tires down to 0.075mm passed sieve size. First, the tire was shredded and chipped using large machinery with crack mill of mechanical blades to obtain rubber shreds. Furthermore, in the process remove most of the steel wires and reinforcing fibers or fluff of the recycled tires using magnets. To meet the requirement of gradation, the crumb rubber was sieved and separated into categories. As per [62] on their study smaller CR particles which is fine particle size benefited to low-temperature cracking resistance and stability as showed in Figure 3.4 (a) Crumb rubber was made in Horizon Addis Tyre company located in Addis Ababa Ethiopia.

Polyethylene Terephthalate Plastic

Plastics are categorized as thermoplastic or thermosetting materials based on their physical properties. Under heat and pressure, thermoplastic materials can be shaped into desired shapes and then solidify when cooled. They can be remolded if they are exposed to the same heat and pressure conditions. Thermosetting materials cannot be softened or redesigned after they have been formed [63].

Polyethylene terephthalate is the chemical name for polyester and is categorized under thermoplastics. In this study, polyethylene terephthalate plastic bottles with the local name of Highland plastic were used as filler in the mixture. Those plastics are softened at temperatures between 130°C and 140°C and there is no gas evolution in the temperature range of 130°C-180°C. Therefore, this kind of plastic can easily be blended with coarse and fine aggregate in the mix in the range of 155°C-165°C.

Physical and Chemical properties of PET

Virgin PET is a superior material for some applications. This material has various great features, such as good tensile strength, adequate thermal stability, chemical resistance, processing capability, color capability, and clarity [64]. At normal temperatures and pressures, it can be formed. PET can be made from petroleum hydrocarbons by reacting ethylene glycol with terephthalate acid. The table below shows the basic physical and chemical features of commercially used PET polymers[65].

Table 3.1 Physical and Chemical properties of PET[64]

Property	Test method	Value (Unit)
Molecular weight	-	192(g/mol)
Mark-Houwink Parameter	-	K = $3.72*10^{-2}$ (ml/g) a = 0.73
Weight Average MW	-	30,000 -80,000(g mol^{-1})

Density	-	1.41 (g/cm^3)
Glass translation temperature	DSC	69 115 (°C)
Melting temperature	DSC	265 (°C)
Heat of fusion	DSC	166(J/g)
Breaking strength	Tensile	50(MPa)
Tensile strength (young's Modulus)	-	1700(MPa)
Yield Strain	Tensile	4%
Impact strength	ASTM D256-86	90(Jm^{-1})
Water absorption (after 24hr.)	-	0.5(%)

Note: it is not possible to make chemical composition for PET due to the lack of chemicals ingredients during at the time of study in the geological Survey Ethiopia organization. Therefore, the above properties of PET taken as secondary data from previous researcher but chemical composition for crumb rubber stated in the next chapter.

The grounded waste PET particles or with local name of highland plastic were collected from homes. Polyethylene Terephthalate wasted plastic was washed to remove impurities then the clean PET plastic bottle fed into shredders, which break it down into much smaller pieces to obtain the fine PET plastic with the particle size of less than 0.075mm, as shown in Figure 3.4 (b) As per H. Taherkhani and M. R. Arshadi study on effcect of course and fine PET particle size on the modification of asphalt mixture. They stated that the mixture containg fine graded PET particles has more resistance againist permanent deformation than the mixture containing coarse graded PET particles [42].

a) Crumb rubber b) Fine graded waste PET

Figure 3.4 Waste Material (photo credit by Getnet M)

3.8 Sampling Techniques and Sampling Size

3.8.1 Sampling Techniques

Laboratory experiments on the asphalt mixture were done to provide sufficient and accurate data for the goal of study. Purposive sampling technique were utilized to do laboratory tests on the components needed to construct the asphalt mixture, which included bitumen, aggregate, crumb rubber, and PET waste plastic.

3.8.2 Sampling Size

B. Y. Tefera, K. Tadele, and A. Geremew, in their investigation into "Evaluation of the Effect of Rubber Modified Bitumen on Asphalt Performance" they evaluated the properties of the crumb rubber modified bitumen with five different percentages of rubber by weight of bitumen: 0%, 5%, 10%, 15%, and 20% were used and found that asphalt mixed with 15% crumb rubber has higher stability than the other percentages of CR [66]. Based on their investigation. In this study, the optimum percentage of CR content in modified asphalt binder was determined using two different percentages of crumb rubber content which was 10% and 15% by weight of optimum bitumen content in asphalt binder modification. And also H. Taherkhani and M. R. Arshadi, investigated the effect of using PET on the mechanical properties of asphalt concrete. In their study, 0, 2, 4, 6, 8 and 10% of PET concentration were used, but 2% of PET concentration showed the highest ITS [42]. Based on their investigation. In this study, the concentration of PET was varied in proportions of 0%, 2%, 4%, and 6% by weight of filler material.

According to ASTM, a minimum of three specimens is required for Marshall mix design to determine the sample test as per specification. Fifteen samples were prepared (3 samples for each percentage of bitumen) for the determination of the optimum bitumen content (OBC) with varying percentages of bitumen (4%, 4.5%, 5%, 5.5%, and 6%) without polymer modification, which is the conventional Marshall samples of 101.6 mm diameter and 63.5 mm height were used to calculate the density and quantity of air voids in the mixture, Marshall stability and flow and also moisture damage by indirect tensile strength (ITS). The mixing process was carried out at a temperature of 150°C with a manual and five un-compacted asphalt mixture samples as per the number of asphalt binder content were prepared for the maximum theoretical density test.

Using a combination of crumb rubber and PET polymer, 12 samples of modified asphalt mixture were created. The optimum PET polymer content (OPC) in the crumb rubber modified asphalt mixture was determined using three samples for each percentage of PET (0%, 2%, 4%, and 6%) by weight of filler material in the mix. Six compacted marshal samples were used to determine moisture sustainability for mixture with neat bitumen using the optimum binder content. Three samples for wet condition and another three samples for dry condition and a total of twenty-four compacted marshal samples were used to determine moisture sustainability of the modified asphalt mixture using three samples for each percentage of PET (i.e., 0%, 2%, 4%, and 6%) by weight of filler material in the mix. The first twelve samples for wet conditions and another twelve samples were used for dry conditions.

3.9 Laboratory Test Method

3.9.1 Types of Tests

The major approach used to meet the study's objectives is laboratory testing. All of the tests were carried out utilizing equipment and gadgets from **Core Consulting Engineering Company's Geotechnics and Highway Engineering Laboratory** in Addis Ababa. The properties of crumb rubber and PET plastic waste polymer modified asphalt mixtures were also evaluated and compared to conventional asphalt mixture. The asphalt mixtures, both modified and mixture with neat bitumen, were compared to specified standards. The physical quality features of used materials such as aggregate and asphalt binder are evaluated in the first step of laboratory tests.

Physical quality testing on the asphalt binder was carried out, including penetration, specific gravity, ductility, and softening point tests. Aggregate crushing value, Los Angeles Abrasion test, Water Absorption test, and particle shape and specific gravity were also performed for the aggregate quality test. For each aggregate type, sieve analysis was performed to determine aggregate size grading, which was then followed by aggregate blending to provide the binder course gradation curve that was utilized to make asphalt mix. Following that, an asphalt mixture with various asphalt binder contents was done, and the Marshall test was performed to determine the optimum binder content. Density, air void, Marshall Stability (MS) and flow they were utilized in calculating the optimum binder content (OBC) of the conventional asphalt mixture.

Asphalt mixes with various percentages of waste crumb rubber and PET plastic polymer were prepared using the value of the optimum asphalt binder content. To measure moisture sustainability, an indirect tensile strength test was performed on the mixture with neat bitumen and modified asphalt mixtures.

3.9.2 Method of Test

Tests and standards for aggregate

Sieve analysis was used to determine the particle size distribution of the course, fine aggregates and fillers used in the asphalt mix. The test was carried out in compliance with IS: 2386 Part 1 (1963) where a known weight of aggregate 1000g preferably was poured into a well-arranged set of test sieves as shown in the Table A.1.5. The aggregate retained on each test sieve was used to calculate the grain-size distribution of each aggregate.

The specific gravity (Gs) of each of the aggregates was calculated using the pycnometer method in compliance with ASTM 1429. Bulk density was calculated as the mass of aggregate or material that filled a container which is levelled at the top surface divided by the volume of the container. Moisture content (MC) was also calculated and it revealed the natural water content of the aggregates. In addition, water absorption (WA) was carried out to determine the ability of the aggregates to absorb water as shown in the Table A.2.1. The test was carried out on natural aggregates in compliance with AASHTO T85 and IS: 2386 (Part III) 1963.

Aggregate crushing value (ACV) is the mass of the material, expressed as a percentage of the test sample, which is crushed into fewer than 2.30 mm under a compressive load of 400 KN. The test was carried out on natural aggregate under IS 2586 and in compliance with BS 487 (2009) and BS EN 932-1 (1999) as shown in the Table A.1.1.

An Aggregate impact value (AIV) test was also carried out on natural aggregates under BS:812 Part 112 as shown in the Table A.1.2. The AIV is the % of fines produced from the aggregate sample after subjecting it to a standard amount of known weight, height and a prescribed number of times. This test simulates the resistance to the impact of aggregates in field conditions.

Tests and Standards for Bitumen

Before preparing the modified asphalt mixture, the contribution of a single crumb rubber additive to bitumen property was evaluated. The asphalt binder has a penetration grade of 80/100 bitumen was heated to 160 °C until it became a free-flowing semi-viscous liquid melted. Using the wet process, the crumb rubber powder polymer was added to hot liquid bitumen. In this study, two proportions (10% and 15%) of crumb rubber by weight of asphalt binder were used to modified asphalt binder and followed a swelling process at 160 °C for 1 h as shown in the Appendix H (r). During the swelling process, the crumb rubber polymer agents can adequately contact the hot bitumen to make the agents expand and soft. The modified asphalt binder evaluates using quality tests.

The ductility of the asphalt binder was measured by the distance in mm to which a sample of bitumen will elongate before breaking when a standard briquette specimen of the material is pulled apart at a specified speed and a specified temperature of 25°C ± 0.5 as regulated by the ductility machine as shown Table B.1.1

The ring and ball tests were performed based on the ASTM D36 standard to evaluate the softening point of bitumen before and after modification as shown in the Table B.1.2. It measures the susceptibility of blown asphalt binder to temperature changes.

According to ASTM D5, the penetration test was carried out with the view of measuring the influence of modification of bitumen hardening as shown in the Table B.1.3. The Penetration index test measures the distance in tenths of a millimeter, which a standard needle would penetrate vertically into a sample/binder under standard conditions of temperature, load and time. The average of three penetration readings was taken as the representative value.

Tests and specifications for Asphalt Mixture

Mix Design and Sample Preparation

The Marshall mixture design technique was used to calculate the optimum binder content (OBC) for a conventional asphalt mixture without polymer modification. In this method, the resistance of plastic deformation of a compacted a cylindrical specimen of asphalt mixture was measured when the specimen is loaded dramatically at a deformation rate of 50mm/min [67]. Fabrication of cylindrical specimens for testing was done using the Marshall method, which followed the ASTM D1559 standard. The heated aggregate and binder were mixed for 5 minutes to ensure that the aggregate and binder were thoroughly combined. The mixture was poured into the mould, and each side was compacted with 75 blows. After 24 hours, the compacted specimens were taken from the moulds and stored until they were used in tests as shown in the Figure 3.5 and five samples un-compacted mixture were prepared for the determination maximum theoretical density test as shown in the Figure 3.6.

Figure 3.5 Marshall sample specimens (photo credit by Getnet M)

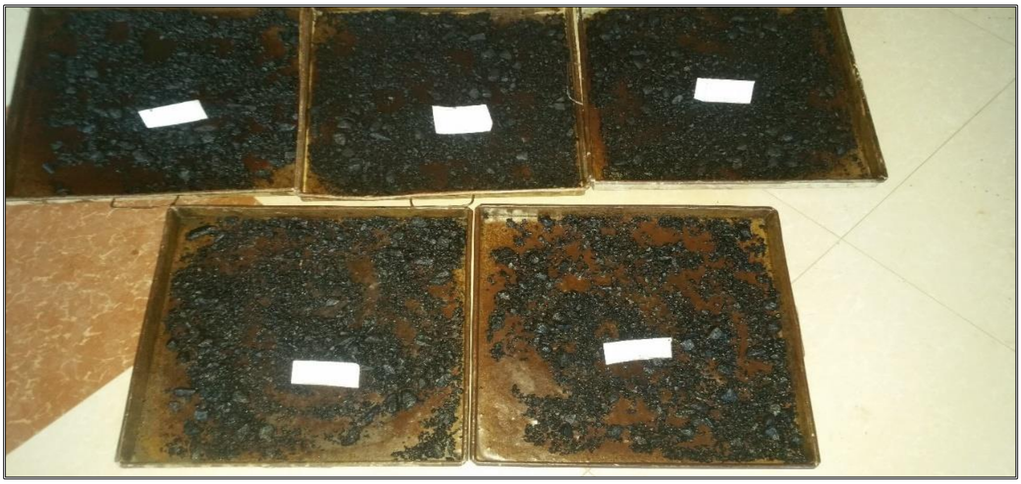


Figure 3.6 Un-compacted Samples for MTD test (photo credit by Getnet M)

The bulk density is computed using the water volume displaced after samples are dry-weighted and subsequently saturated underwater as shown in the Figure 3.7 (a) Following that, samples were conditioned at 60°C for 45 minutes for the Marshall test, as per the standard (ASTM D1559 specification). Figure 3.7 (b) show that the test samples were then put through their spaces in the Marshall press at a displacement rate of 50.8 mm/min until they reached their maximum load. The flow is the value of deformation in mm that the sample registered upon attaining the maximum load value, and the resulting stability rate corresponds to the maximum load resisted, in KN was recorded.

a. Bulk density test

b. Stability and flow test

Figure 3.7 Marshall Test for asphalt mixture (photo credit by Getnet M)

Using the asphalt institution method, the mean of the bitumen content corresponding to maximum stability, maximum density, 4% air voids computed as the optimal bitumen content (OBC). The modified asphalt mixture design included both dry and wet process methods. The heated aggregate and the modified asphalt binder with the governed crumb rubber content were mixed for 5 minutes, after which the required amount of PET particles was added to the mixture as a partial replacement for natural stone dust using a dry process method and thoroughly mixed for 2 minutes until the aggregate and PET particles were completely coated with modified asphalt binder. This method of mixing ensures that PET remains semi-crystalline and that only minor changes in the characteristics and structure of PET particles occur. The glass transition temperature for PET is roughly 70°C. The amorphous part of PET was melted at the mixing temperature, increasing binder cohesion, while the crystalline part does not change. The voids between aggregate particles are filled with the crystalline part of PET, increasing mixture stiffness.

In this investigation, four proportions of PET (0%, 2%, 4%, and 6%) polymer by weight of natural crushed stone filler material were chosen to be investigated for the manufacture of polymer-modified HMA samples and detection of OPC as shown in the Figure 3.8. For adjusted combinations, the total percentage of binder (OBC) in the mix remained unchanged (5.5%).

Figure 3.8 Modified Marshall sample specimens (photo credit by Getnet M)

Moisture Damage Test

The Indirect tensile strength (ITS) is used to determine the tensile properties of a bituminous mixture whose results are connected to the rutting and cracking qualities of asphalt pavement [68].

The tensile characteristics of a bituminous mixture are evaluated by loading the Marshall specimen along with a diametric plane with a compressive load at a constant rate acting parallel to and along the vertical diametric plane of the specimen through two opposite loading strips. Marshall asphalt specimens with a thickness of 63.5±1.3mm and a diameter of 101.6mm were manufactured for each category. The static indirect tensile strength of a specimen is determined using the procedure outlined in ASTM D 6931.

According to the ASTM specification, the three samples available for each combination were divided into two groups for conditioning, one wet condition and the other dry condition with optimum asphalt binder content. Samples under wet conditioning underwent a period of hydrostatic vacuum with 50mm Hg absolute pressure for 30min, then the samples were introduced to a water bath at 40°C for 24hr., and finally the samples remained for two hours in a water bath at a temperature of 15°C before the test. Cylindrical specimens were inserted in two loading strips and subjected to a consistent compressive force at a speed of 50mm/min till failure. The vertical compressive load was changed into homogeneous horizontal tensile tension in this method. Following conditioning, all samples were subjected to indirect tensile strength testing at a displacement rate of 50.8mm/mi until the maximum load was reached was used to get the ITS value using the maximum applied load.

$$ITS = \frac{2P}{\pi * t * D} \qquad \text{Equation 3.1}$$

Where, ITS is the indirect tensile strength (MPa); P = the maximum applied load (N);

t = the specimen thickness (mm) and D = is the specimen diameter (mm).

The ITS test is a performance test that is often used to evaluate the moisture susceptibility of a bituminous mixture. The tensile strength ratio is a measure of water sensitivity. It is the ratio of the tensile strength of the water condition specimen (ITS wet) to the tensile strength of the unconditioned specimen (ITS dry).

3.10 Finite Element Modelling

Numerical modelling is based on calculations that employ algorithms to solve atrial differential equations that are functions of multiple variables. Material properties, stress, strain, and Young's modulus are examples of these variables.

The software used in this study for modelling and simulation is Abaqus Progress, version 6.13. The goal of this simulation is to discover the layer reaction (stress and vertical deflections) in pavement layers under projected traffic loads in constant static loading situations and varied pavement layer thicknesses. As a result, the pavement section's improvement can be assessed. For various Abaqus models, the modulus of elasticity is used as the key indicator of stiffness. The elastic modulus based on recoverable strain under repeated load is known as Young's modulus or modulus of elasticity, and it is defined as:

$$M_E = \frac{\sigma_d}{\varepsilon_r} \text{.....................................Equation 3.2}$$

Where: - σ_d: Deviator stress ε_r: Recoverable elastic strain

To define the required parameters of the modified mixtures, indirect tensile strength test was conducted on the modified mixture as well as the control mixture. The indirect tensile strength test gives the tensile strength of the mixture therefore, the compressive load or the static load determine by the equation shown below

$$P = \frac{ITS*(\pi*t*D)}{2} \text{.........................Equation 3.3}$$

The stress was measured from dividing the calculated static load on the specimen affected area as shown in the equation shown below

$$\sigma = \frac{\text{Static load or Compressive force}}{\text{Specimen area}} \text{...........Equation 3.4}$$

The vertical strain is the ratio between the difference changes in height related the specimen height. The Modulus of elasticity is expressed by vertical stress per vertical strain as shown in the Equation 3.2 The height, diameter, horizontal displacement and vertical displacement are measured by Vernier caliper tool.

The Poisson's ratio is a material property that can be used to predict an asphalt mixture's horizontal movement. It is defined as the ratio of horizontal to vertical strain. Poisson's ratio values in most investigations were between 0.3 and 0.4.

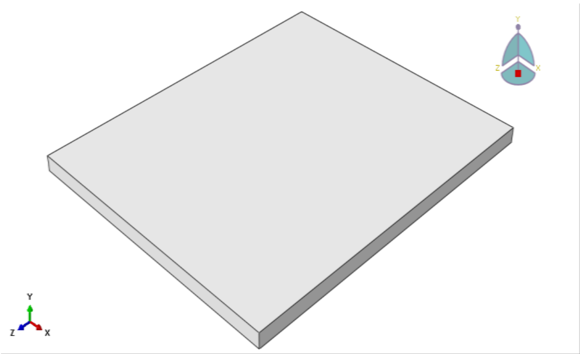
This research looks at how the characteristics and modulus of elasticity of the asphalt layer (wearing surface) evolve without affecting the properties of the base, subbase, and subgrade layers. Flexible pavement layer characteristics such as thickness, depth, and width are the characteristics used in modelling. The subgrade, subbase, base course, and top asphalt layer make up a typical flexible pavement cross-section. The linear elastic (LE) model was used to simulate the subgrade, subbase, base layers, and surface layers in Abaqus. The axis-symmetric modelling methodology presupposes that the pavement system's materials and geometric attributes are constant in horizontal planes and that traffic loading is symmetric in both directions (e.g., the circular load acting at the center of the pavement structure). For all models, the wheel load is simulated as applied pressure acting on a circular area with a radius of 0.20m between the pavement surface and the wheel load and a constant value of 0.7Mpa Unfortunately, it can only be used to capture the response of the pavement system if the load is not placed close to the shoulder or fracture.

Unmodified, (0% PET, 2 % PET, 4% PET, and 6% PET) are the names of the developed models (cross-sections) modified Asphalt Mixture with Crumb Rubber, and PET. Asphalt, base course, subbase course, and subgrade layers make up the structure of all models. The Abaqus program was used to perform five runs with consistent thickness and dimensions for all flexible pavement layers and a constant pressure load. The researched surface is expected to be made from crumb rubber and PET polymer-enhanced mixtures. The vertical deformation (U2) and stress (S) for the indicated pavement section are calculated using the Abaqus program based on the results of five runs.

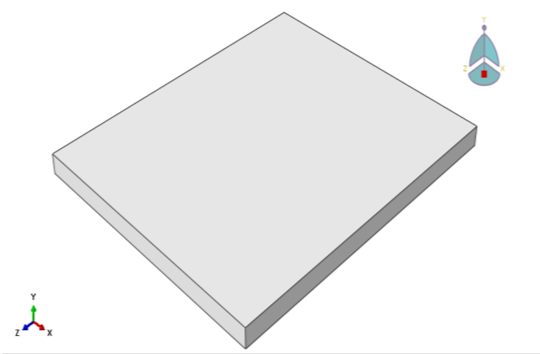
3.10.1 Creating and analyzing Flexible Pavement model using the Abaqus/CAE modules

The part module

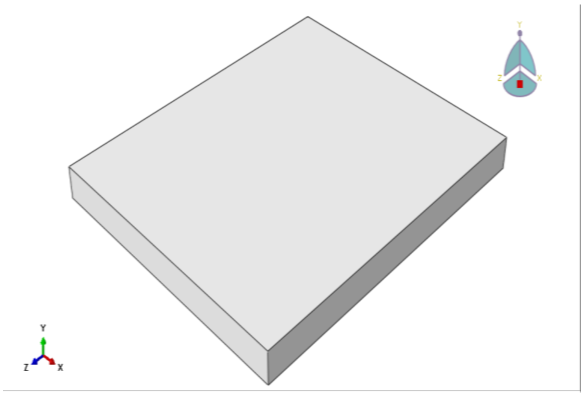
Parts are the elements that make up an Abaqus/CAE model. To create a portion that utilizes the full part, a feature-based representation was used. As illustrated in the Figure 3.9 below, a three-dimensional deformable four different portions of pavement were utilized to model flexible pavement, each of which is 5cm, 20cm, 30cm, and 1m thick for surface, base, subbase, and subgrade layer respectively



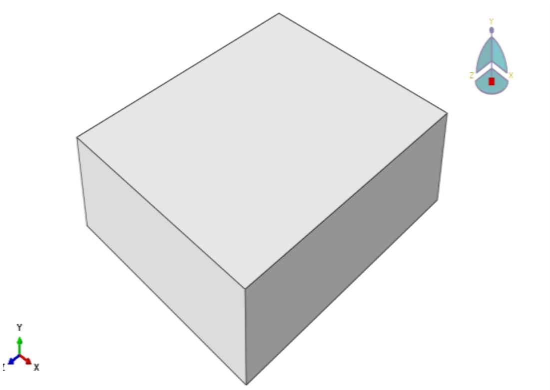
a. Asphalt Layer



b. Base layer



c. Subbase layer

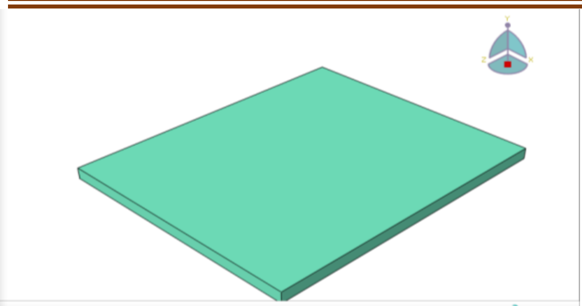


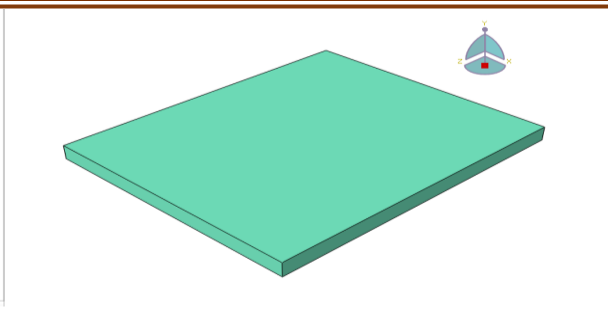
d. Subgrade layer

Figure 3.9 Flexible pavement layer parts in Abaqus software

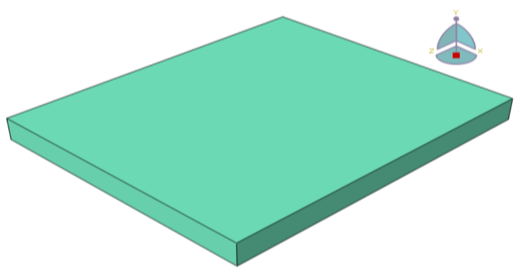
The property module

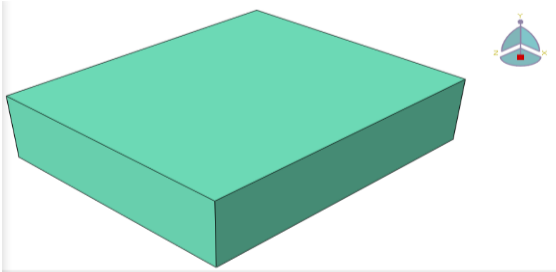
A material definition contains all of the information about a material's properties. Include a set of material behaviors in a material definition. The material was assumed in this model is to be homogeneous isotropic linear elastic materials. For each pavement layer, the solid sections property of three-dimensional was applied in this study. Therefore, the pavement structural material was modeled in terms of the elastic modulus and the Poisson’s ratio.





a. Asphalt Layer b. Base layer



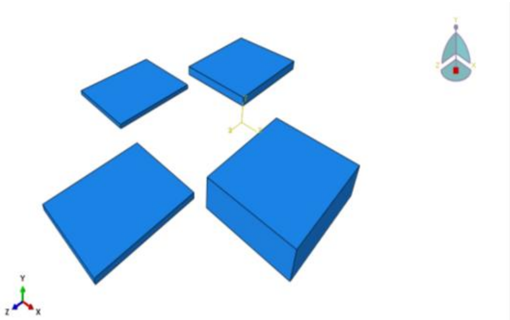


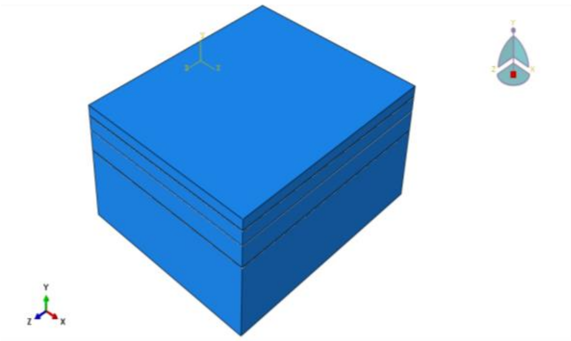
c. Subbase layer d. Subgrade layer

Figure 3.10 Assign material behaviours for pavement layers

The assembly module

Create instances of the created parts and arrange them relative to each other in a global coordinate system using the Assembly module. In a global coordinate system, the assembly module is used to position and orient instances of produced parts and models relative to one another. Individual layers, such as asphalt, base, subbase, and subgrade, are built as a single object using the assembly module. Figure 3.11(a) shows separated layers such as a surface layer, base layer, subbase layer and subgrade layer that are not compatible with each other which is not assemble and Figure 3.11(b) shows previous individual layers compatible with each other and create a single pavement section due to assembly module.





a. Pavement layers in different coordinate b. Assemble pavement layers in a single coordinate

Figure 3.11 Assembled pavement layers

The mesh module

The Mesh module allows you to generate meshes on parts and assemblies created within Abaqus/CAE. the process of assigning mesh attributes to the model such as seeds, mesh techniques, and element types was feature-based. One of the features of meshing was model coloring that indicates the meshing technique assigned to the region of the model. For this study, part section technique was used to mesh the pavement layer.

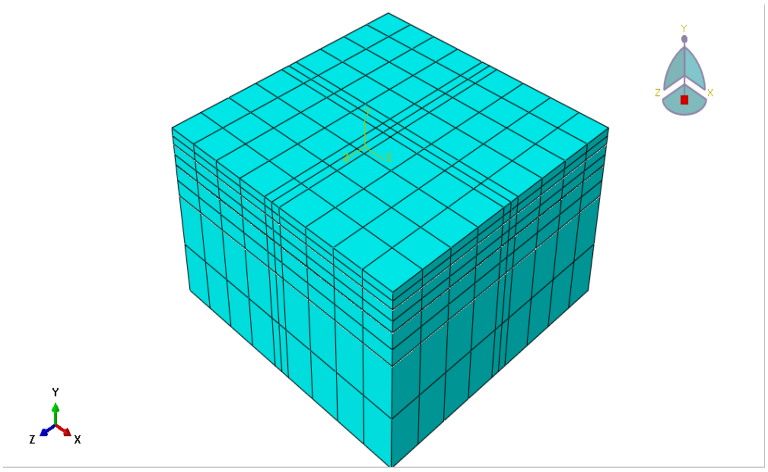


Figure 3.12 Meshed the model pavement layers

The interaction Module

Interactions are step-dependent objects, which means you must specify which phases of the analysis they are active in when defining them. To interact with the pavement layers, surface-to-surface contact interactions between two deformable surfaces or between a deformable surface were used. This module used to interact the surface layer with a base layer and the base layer with subbase layer and subbase layer with the subgrade layer to study the effect of vehicle tire pressure throughout the pavement layers.

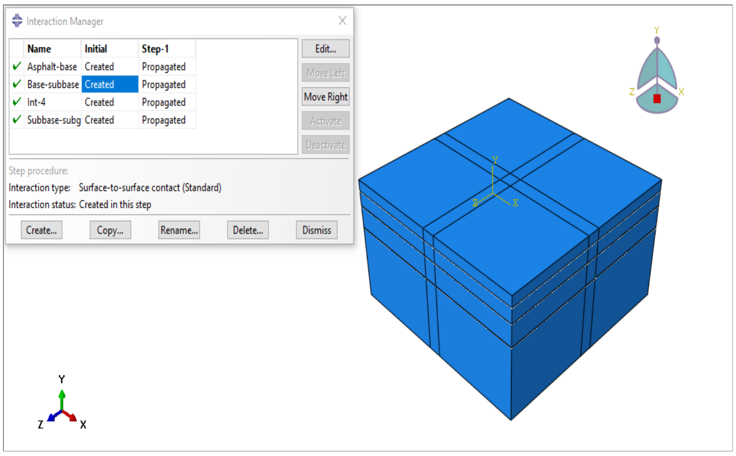


Figure 3.13 Interaction each pavement layers each other

The step Module

The step sequence provides a convenient way to capture changes in the loading and boundary conditions of the model, changes in the way parts of the model interact with each other, the removal or addition of parts, and any other changes that may occur in the model during the analysis.

The load module

Load cases are sets of loads and boundary conditions used to define a particular loading condition. Using 3D FE modeling of the flexible pavement was used to simulate a rectangular footprint of the contact area over which the tire pressure was distributed. The load was assumed to be transferred to the pavement over a rectangular contact area. In this study the model was done with the dimension (0.2 * 0.2) in transverse and longitudinal direction respectively. For the analysis, a single load case was used to study the linear response of the pavement structure subjected to vehicle tire pressure. The tire pressure of 0.48Mpa (70 Psi) that were used at the AASHTO road testing 1962 are low compared with the pressure used by the operators of heavy vehicles nowadays over 90% of heavy trucks will have higher tire pressure. Mean value of more than 0.7Mpa (102Psi) are common and some of the very heavily loaded trucks can have tire pressure of up to 1.03Mpa(150Psi)[17]. The tire pressure used as a distributed load on the center of the pavement section having a magnitude 0.7 Mpa. The study area has high traffic flow 91.2% vehicle are passenger cars due to this the tire pressure of the vehicle not greater than 0.7Mpa. The given tire pressure defines in terms of load and boundary condition.

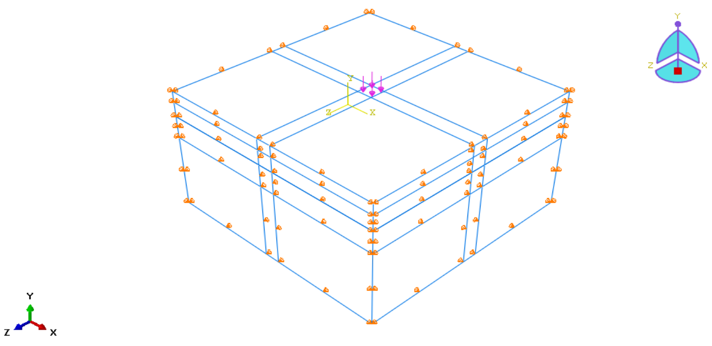


Figure 3.14 Assign Tire Pressure

The job module

After finishing all of the tasks involved in defining a model (such as defining the geometry of the model, assigning section properties, and defining contact), use the Job module to analyze the developed model. The job module is used to create a job, submit it for analysis, and to monitor its progress.

Visualization module

The visualization module provides a graphical display of finite elements and results. It contains model information from the current model database or model and result information from an output database. The analysis and graphical display of the deformed finite element model of the unmodified and modified asphalt mixture are shown in the next chapter's result and discussion.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 General

This chapter discusses the effect of adding additives (such as Crumb rubber and Polyethylene Terephthalate plastic) to the hot mix asphalt (HMA) and compares the obtained results with conventional. The effects of adding varying percentage of CR and PET polymer additives on the properties of both the asphalt binder and mechanical properties of the asphalt mixture are collected and presented in this chapter. The analysis of the results shall be presented in three parts. The first section discusses the physical quality properties of components of hot mix asphalt mixture as well as Marshal Test result in order to obtain the optimum binder content of the asphalt mixture. The second section look at the impact of adding additives (Crumb rubber and PET) on both asphalt binder and hot asphalt mixtures properties as well as identifying the best percentages of crumb rubber and PET. The third portion used a finite element model to compare the properties of conventional and polymer modified HMA's in a comparative study.

4.2 Chemical Composition of Crumb Rubber

The complete silicate analysis for Crumb rubber was performed in the geochemical laboratory of geological survey Ethiopia located in Vatican Sarbet Street, Addis Ababa, Ethiopia as shown in Appendix I. The analysis report shows that the crumb rubber has a specific gravity of 1.15g/cm³ and the moisture by weight was 0.54% also ASTM D6114 recommended that in order to produce asphalt binder, the rubber should have a moisture of less than 0.75% and the specific gravity between in the range of 1.15 ± 0.05. The crumb rubber has less component of SiO_2 which is less than 30% and other oxide component except Al_2O_3 and Fe_2O_3 less than 1%. Laboratory results show that the chemical composition of the crushed rubber blends well with the asphalt and forms a homogeneous mixture. It also indicates that the asphalt will not change it is behavior and not damaged. Therefore, It is possible to use the given crumb rubber for asphalt modification. Table 4.1 show that the composition property of crumb rubber.

Table 4.1Chemical Composition of Crumb Rubber

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	H_2O
Content (%)	12.5	2.88	6.54	<0.01	<0.01	<0.01	<0.01	<0.06	0.54

Note: Chemical composition component of PET taken from previous researchers. As shown in in the previous chapter.

4.3 Physical Quality Test of Aggregate

From Aggregate crushing test, the percentage of weight passed through 2.36mm sieve size was 14.82%, which is below 25 as per British standard manual as shown on Table 4.2 and Appendix A (Table A.1.1). The obtained result indicated that the sampled aggregate strong enough to resist crushing under a gradually applied compressive load and withstand crushing under roller and traffic.

The aggregate impact value test result indicated that the amount of the material finer than 2.36mm was 10.33%, which is below 25 shown on Table 4.2 and Appendix A (Table A.1.2). The obtained test result show that the resistance of sudden shock or impact load of the sampled aggregate was strong enough.

On coarse aggregate, the Los Angeles abrasion test was performed. According to the test results, the percent of loss was 17.84%, which is less than 30%, as stated in Table 4.2 and Appendix A. (Table A.1.4). Therefore, the sampled aggregate has good mechanical properties of to resist crushing, degradation and disintegration in order to produce a high quality of HMA.

Appendix A. (Table A.2.1) show specific gravity and water absorption test for both coarse and fine aggregate. The test result indicate that the aggregate materials have less absorption of water which means during mix process the strength bond between aggregate and asphalt binder are high. In addition, the test result shows specific gravity of fine aggregate higher than coarse aggregate the reason behind that the aggregate particle smaller than the coarse aggregate due to this the fraction of pores exposed to the aggregate surface increase.

Table 4.2 Properties of HMA Aggregate

Test type	**Test method**	**Test result**				**Specific-cation**
		19-25mm	6.3-19mm	3-6.3mm	0-3mm	
ACV	BS 812, Part 3(1985)	-	14.82 %	-	-	< 25
AIV	BS 812, Part 3(1985)	-	10.33 %	-	-	< 25
LAA	ASTM C131 and C535	-	17.84 %	-	-	< 30
Water Abs.	BS 812, Part 2 (1975)	1.8	1.7	1.7	1.8	< 2
Bulk Dry S. G	AASHTO T85 - 91	2.56	2.57	2.58	2.64	-
Bulk SSD S. G		2.61	2.62	2.62	2.68	-
Apparent S. G		2.69	2.69	2.7	2.76	-

The particle size distribution of an aggregate was determined by sieve analysis. It termed as gradation of aggregates. The grading of aggregates was represented by S-curve. Figure 4.1 shows the cumulative percentage of the material passing the sieves represented on the ordinate with the sieve openings to the logarithmic scale represented on the abscissa in terms of grading curve. The grading curve show that the amount of course and fine aggregate that pass the given sieve size.

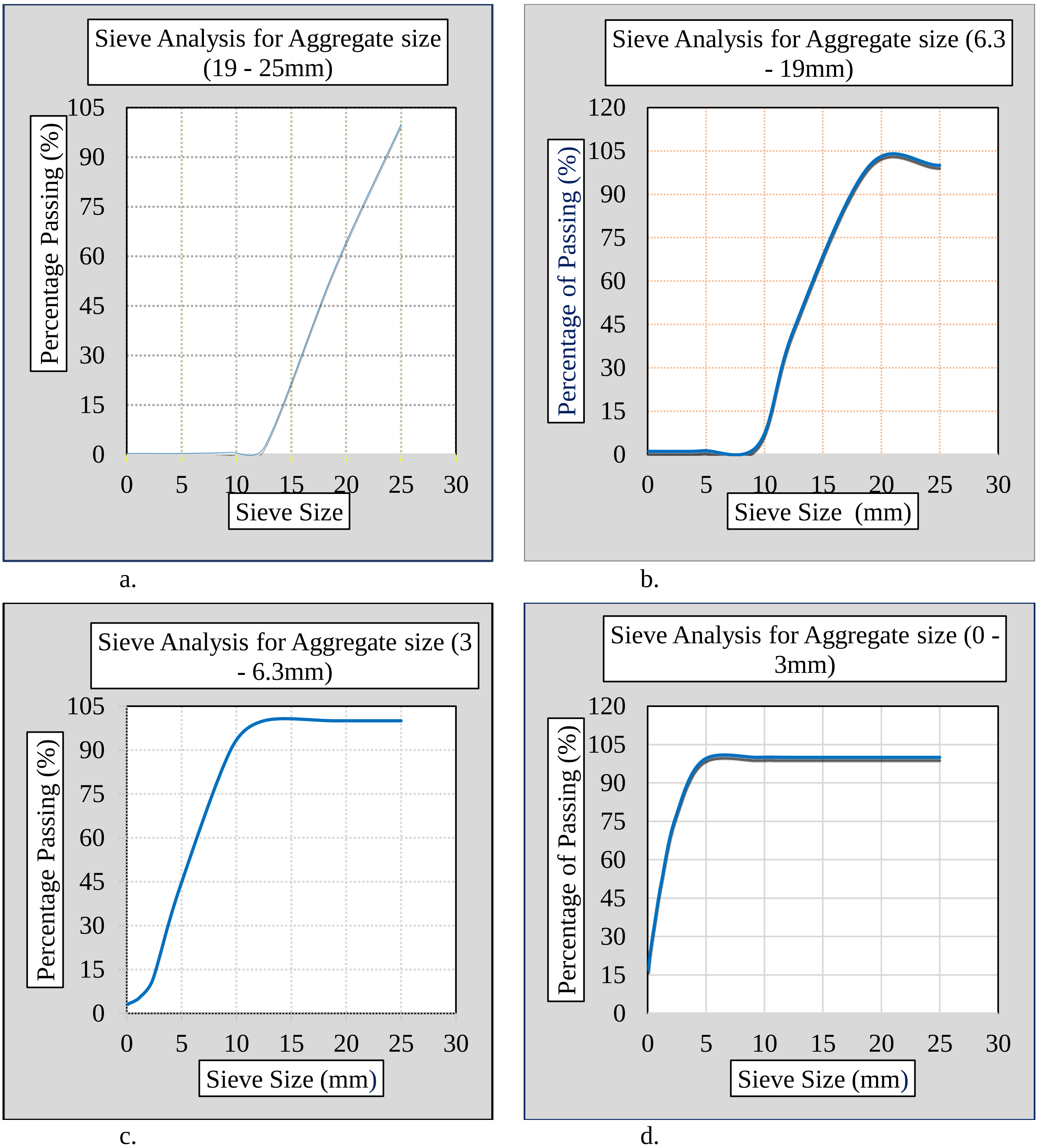


Figure 4.1 Sieve Analysis of Aggregate

4.4 Effect of Crumb rubber on Asphalt binder Properties

When crumb rubber particle added into hot asphalt binder using wet process, the aromatic oils of the asphalt are absorbed into crumb rubber and forming a gel-like materials. Asphalt binder properties under consideration here include penetration, ductility, softening point, and specific gravity. In the next paragraphs, the effect of adding 10% and 15% crumb rubber on the penetration, ductility, softening point, and specific gravity of the asphalt binder is addressed.

Figure 4.2 shows that the softening point value of crumb rubber modified asphalt binder is directly proportional to the percentage of crumb rubber content applied. In comparison to 0% and 10% crumb rubber modified asphalt binder, 15% crumb rubber modified asphalt binder increase it is softening point value by 4.01% and 2.25% respectively. Since the addition of rubber increase resistance to temperature susceptibility and a measure of flow of bitumen as per [66].

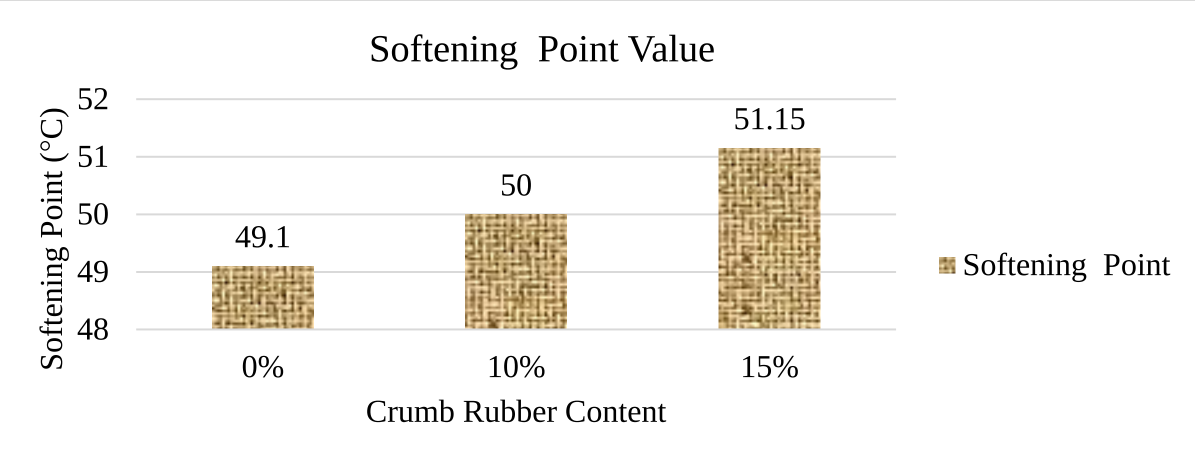


Figure 4.2 Softening Point Value of Modified binder

Figure 4.3 shows that the penetration value of crumb rubber modified asphalt binder decreases as the percentage of waste crumb rubber content applied increases. The penetration value of 0% crumb rubber asphalt binder higher than 10% and 15% crumb rubber modified asphalt binder by 1.56% and 6% respectively. When compared to 0% and 10% crumb rubber modified asphalt binders, 15% crumb rubber modified asphalt binder has a lower penetration value, which means the modified binder with 15% more brittle and hard than other modified binders and is preferred in hot climate conditions. However, the study area, Addis Ababa, has a subtropical hiatus. When comparing a 0% binder without crumb rubber to a 10% and 15% crumb rubber modified binder, the 0% binder is softer. This means that the modified asphalt is more resistant to needle penetration into the specimen.

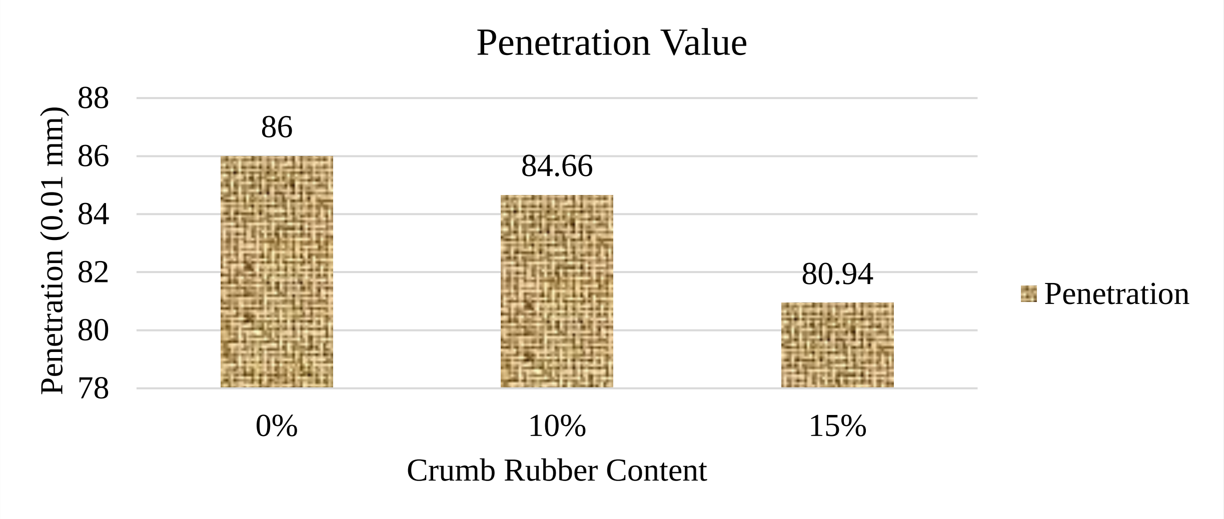


Figure 4.3 Penetration Value of Modified Binder

Ductility shows the tensile behaviour of bituminous binder or homogeneity of binder. Figure 4.4 shows that the ductility value of crumb rubber modified asphalt binder decreases as the percentage of waste crumb rubber content added increases. When compared to 10% crumb rubber modified asphalt binder, 15 percent crumb rubber modified asphalt binder has less ductility. Furthermore, when compared to neat bitumen, 10% crumb rubber modified asphalt binder has a lower ductility value, indicating that the stiffness of the pavement has increased and the pavement has become hard.

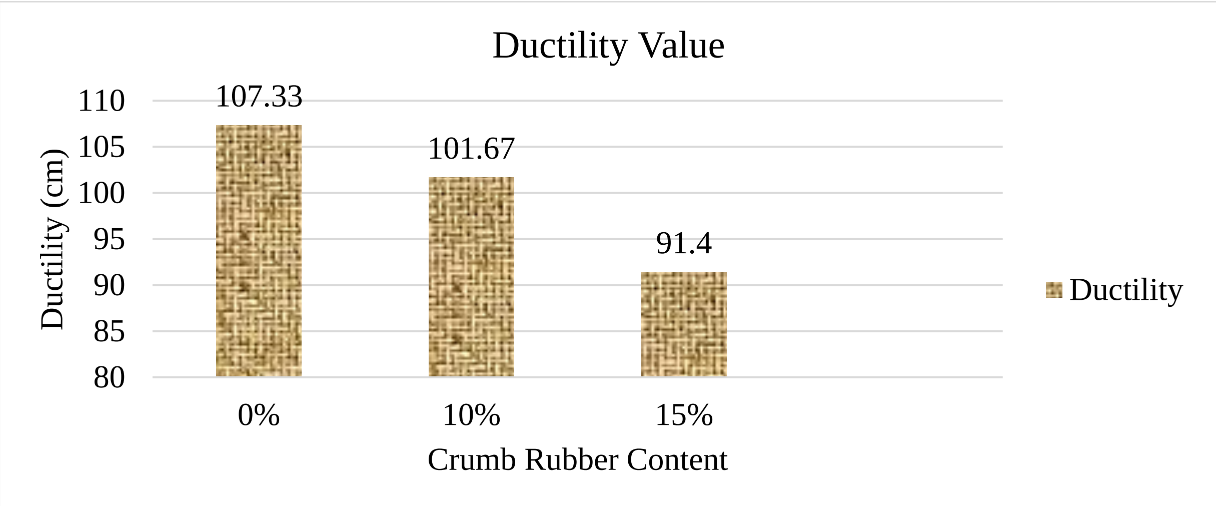


Figure 4.4 Ductility Value of Modified Binder

Figure 4.5 shows that the gravity value of crumb rubber modified asphalt binder decreases when the percentage of waste crumb rubber content is increased. When compared to 10% crumb rubber modified asphalt binder, the specific gravity of 15% crumb rubber modified asphalt binder is lower.

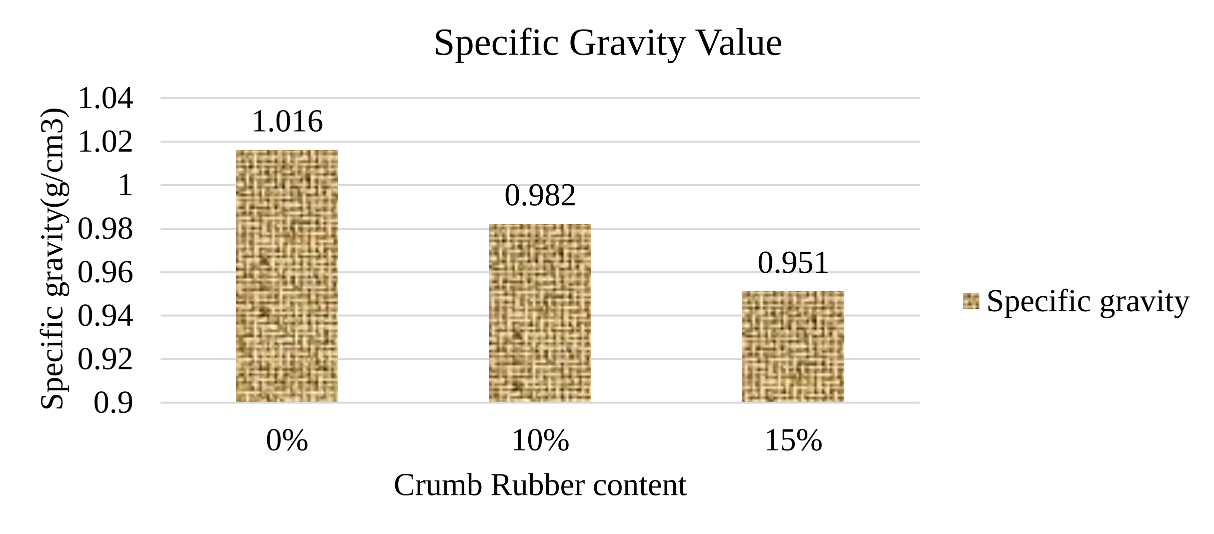


Figure 4.5 Specific Gravity Value Modified Binder

Table 4.3, Table 4.4 and

Table *4.5* show the summary experimental results of crumb rubber modified asphalt binder those results consistent with the result of B. Y. Tefera, K. Tadele, and A. Geremew [66] they found that as rubber content increase from 0 to 20% penetration decrease from 68.5 to 58.5 mm. similarly, for the same percentage increase rubber content ductility decrease from 100 to 75 cm. This results indicate crumb rubber as asphalt binder modifier with in the percentage of 10% and 15% can improve the properties of asphalt binder.

Table 4.3 Summary of properties of unmodified asphalt binder test result

Test	Specification	Result	Specification Limits
Penetration(0.01mm)	ASTMD5	86	80 – 100(binder grade)
Ductility (cm)	ASTMD113	107.33	Min 100
Softening point (°C)	ASTMD36	49.1	(45 – 52)
Specific gravity (g/cm^3)	ASTMD70	1.016	0.97 – 1.06

Table 4.4 Summary of Properties of 10% CR modified asphalt binder test result

Test	Specification	Result	Specification Limits
Penetration(0.01mm)	ASTMD5	84.66	80 – 100(binder grade)
Ductility (cm)	ASTMD113	101.67	Min 100
Softening point (°C)	ASTMD36	50	(45 – 52)
Specific gravity (g/cm^3)	ASTMD70	0.982	0.97 – 1.06

Table 4.5 Summary of Properties of 15% CR modified asphalt binder test result

Test	Specification	Result	Specification Limits
Penetration(0.01mm)	ASTMD5	80.94	80 – 100(binder grade)
Ductility (cm)	ASTMD113	91.40	Min 100
Softening point (°C)	ASTMD36	51.15	(45 – 52)
Specific gravity (g/cm^3)	ASTMD70	0.951	0.97 – 1.06

4.5 Marshal test

As previously stated in Chapter three. In order to find the best optimum binder content, a total of 15 samples weighing 1200 gm were made with five different bitumen percentages (ranging from 4-6% with a 0.5% increment). The result for each mixture was obtained by averaging the result on three replicate specimens. The optimum asphalt content is calculated as the average asphalt content value that corresponds to maximum stability, maximum unit weight, and 4% air voids (AV) or using only 4% of air void. While voids in mineral aggregate (VMA), flow and voids filled with bitumen (VFB) are checked according to the Ethiopian road authority specification. An overview of the Marshal Test results can be seen in the Figure 4.6 and below. For more and detail information see Appendix C.

Relationship between stability and bitumen content

The greatest load necessary to cause specimen failure when applied at a steady rate of 50 mm/min at 60°C is known as stability. The stability results for various bitumen contents are shown in Figure 4.6 (a). As the bitumen percentage increases, the stability of the asphalt mix increases until it reaches a peak at 5.5% bitumen content, after which it begins to fall progressively at greater bitumen concentration. Which indicated that the resistance of the subjected load on the specimen was increase as the bitumen content increase up to 5.5 % of bitumen beyond that the plasticity of the specimen was increase and has low stiffness.

Relationship between flow and bitumen content

The total amount of deformation that happens at maximum load is referred to as flow (Measured from the start of loading to the point at which stability begins to decrease by 0.25mm). Flow results for various bitumen contents are shown in Figure 4.6 (b). The test result shows 6% bitumen content indicates a plastic mix that will experience deformation under traffic. whereas 4% bitumen content indicates a mix with higher-than-normal voids and insufficient asphalt for durability, as well as one that will crack prematurely due to mixture brittleness during traffic.

Relationship between bulk density and bitumen content

The bulk density of a compacted mix is its real density. Bulk density findings for various bitumen contents are shown in Figure 4.6 (c). As the bitumen percentage increases, the bulk density of the asphalt mix increases until it reaches a peak (2.413 g/cm3) at 5.5% bitumen content, after which it begins to drop progressively at increasing bitumen concentration.

Relationship between the proportion of air voids and the bitumen content

The percentage of air voids in a specimen or compacted asphalt mix is expressed as Va%. Va percent values for various bitumen contents are shown in Figure 4.6 (e)). Because the percentage of voids filled with bitumen in the asphalt mix increases as bitumen content increases, the maximum air voids content value is at the lowest bitumen percentage (4%); Va percent decreases progressively as bitumen content increases due to the increase in voids percentage filled with bitumen in the asphalt mix.

Relationship between the percentage of void filled by bitumen and the bitumen content

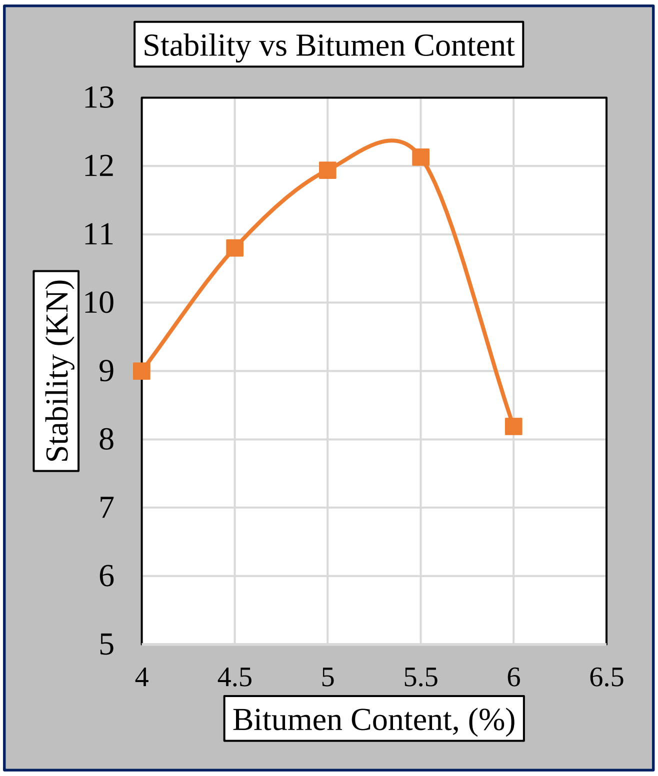
The percentage of voids in mineral aggregates filled with bitumen is known as Voids Filled with Bitumen (VFB). VFB percent findings for various bitumen concentrations are shown in (Figure 4.6(d)). The lowest VFB content value was at the lowest bitumen percentage (4%) which suggests that there were fewer asphalt films around the aggregate particles and that they were more susceptible to moisture and weather influences. VFB percent increases as bitumen content increases due to an increase in the proportion of voids in the asphalt mix filled with bitumen in the case of other bitumen content.

Relationship between the portion of voids in mineral aggregate and bitumen content

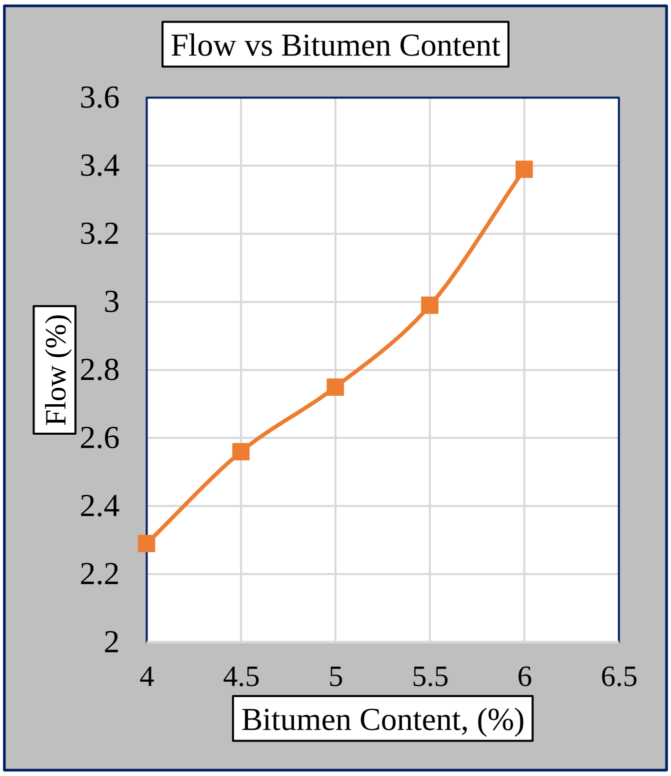
Voids in Mineral Aggregates (VMA) is the percentage of void volume of in the aggregates before adding bitumen or the sum of the percentage of voids filled with bitumen and percentage of air voids remaining in asphalt mix after compaction. In order for aggregate particles to be covered with a sufficient asphalt film thickness, a minimum VMA must be present in the mixture. As a result, a long-lasting asphalt paving mixture is produced [69]. In Figure 4.6 (f) show VMA% results for different bitumen contents are represented. Max voids in mineral aggregates content is at the highest bitumen percentage (6%), VMA% decreases gradually as bitumen content increases specially at the bitumen content of 5 and 5.5%.

Table 4.6 Summary of volumetric and Marshal data

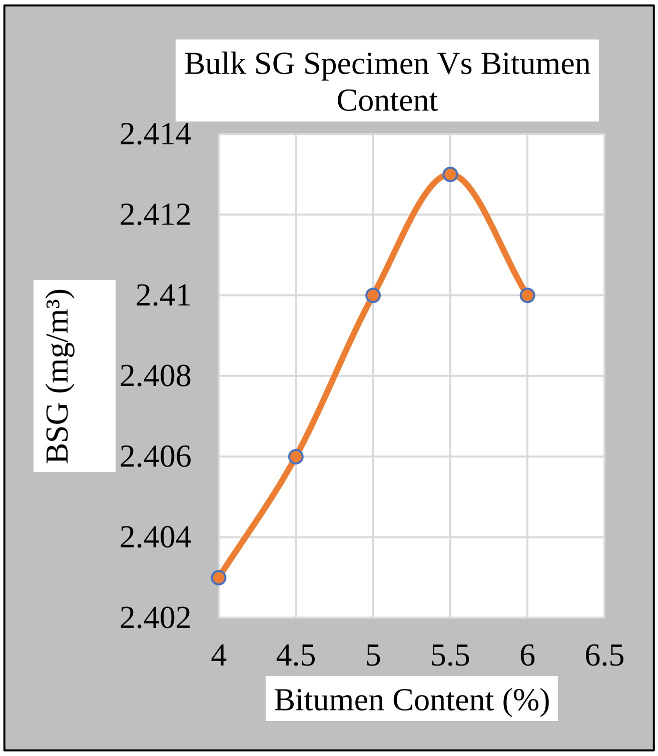
Summary of volumetric and Marshal data							
Binder Content	Bulk SG Specimen (Gmb)	Max SG of loose mix (Gmm)	VIM (%)	VMA (%)	VFB (%)	Stability (KN)	Flow (0.25mm)
4	2.403	2.637	8.89	16.58	46.42	9	2.29
4.5	2.406	2.601	7.51	16.91	55.63	10.8	2.56
5	2.41	2.561	6.28	17.53	64.23	11.94	2.75
5.5	2.413	2.515	4.01	15.56	73.86	12.13	2.99
6	2.410	2.478	3.46	18.67	81.53	8.19	3.39



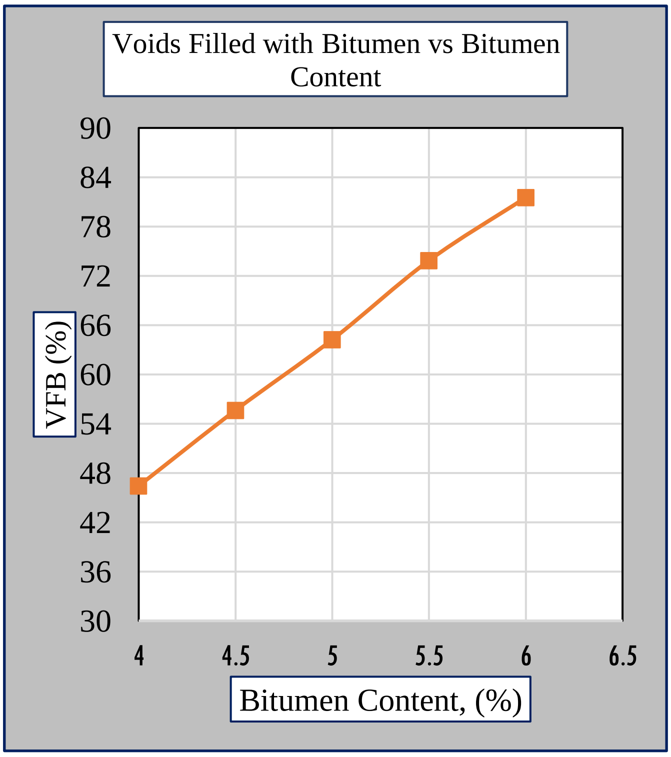
a. Stability vs Bitumen content



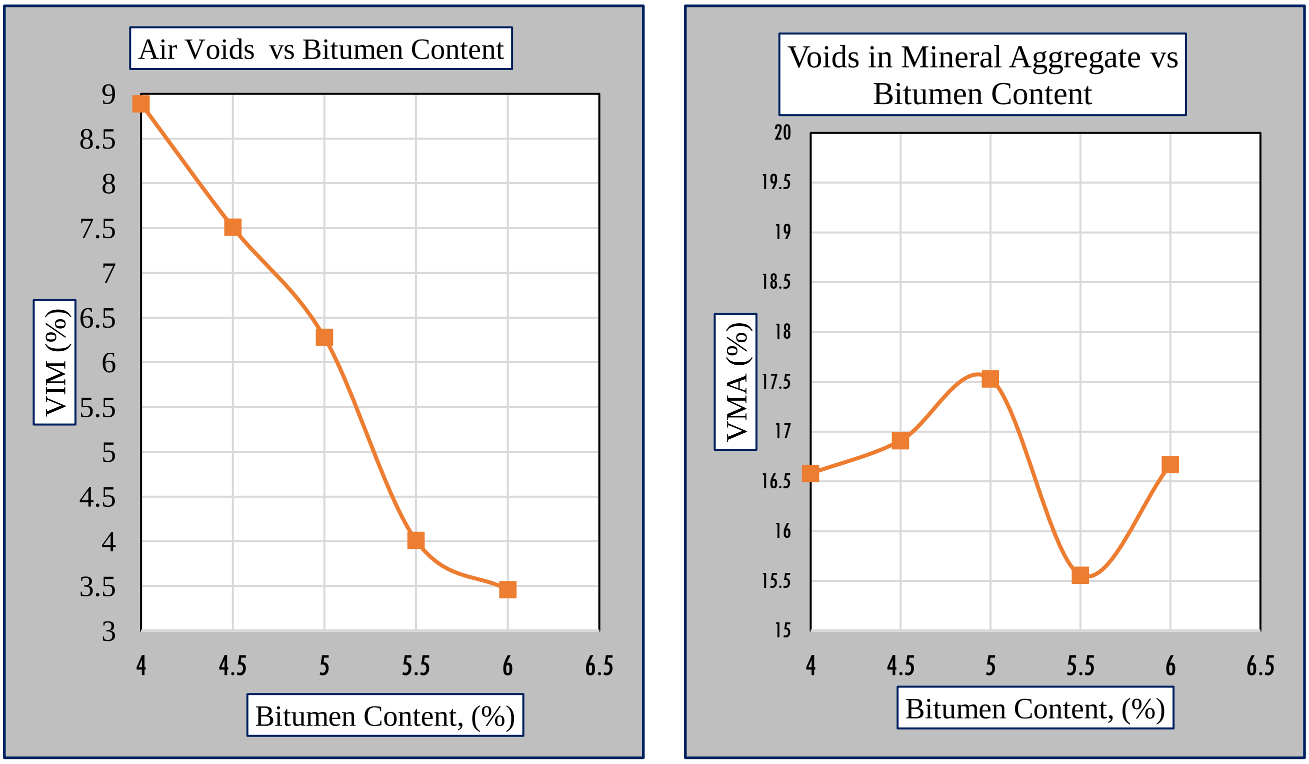
b. Flow vs Bitumen content



c. Bulk specific gravity vs Bitumen



d. Voids filled with bitumen vs Bitumen



e. Air voids vs Bitumen content

f. Voids in mineral aggregate vs Bitumen content

Figure 4.6 Marshall test results for conventional asphalt mixture

4.6 Determination of optimum bitumen content (OBC)

The design bitumen content of the mix is selected by considering all of the data discussed previously. The national asphalt pavement association (NAPA) suggests that the bitumen content giving 4% air voids is chosen as the design bitumen content. From the Marshall test result of 4% air voids, the optimum binder content would be 5.5%.

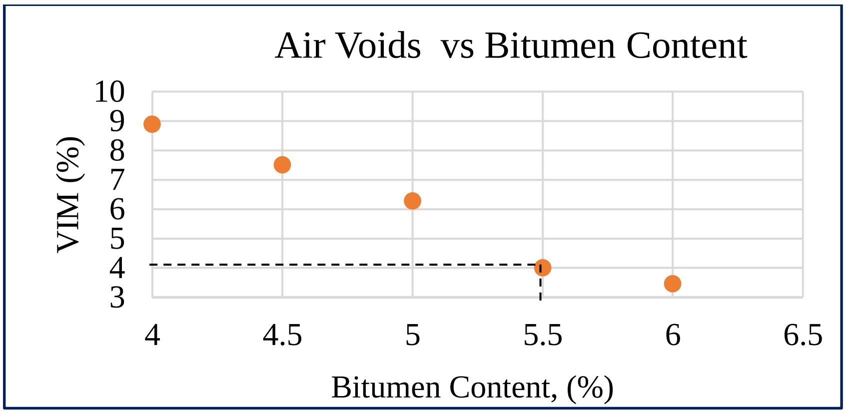


Figure 4.7 Optimum binder content at 4% air voids

The Marshall quotient (MQ) was determined by dividing the Marshall stability by the flow, which is commonly used as a measure of resistance to permanent deformation. A mixture with a higher MQ is stiffer and more resistant to permanent deformation, according to research. The variation of the Marshall quotient for a mixture with neat bitumen is shown in Table 4.7 and Figure 4.8. Bitumen binder content of 5% by weigh of bitumen has more resistance to permeant deformation than the other binder content. Due to more bitumen between aggregate than other but some researchers Marshall quotient not a really indicators of permeant deformation.

Table 4.7 Summary of Marshall quotient unmodified of asphalt mixture

BC	Stability (KN)	Flow (0.25mm)	MQ (KN/m)
4	9	2.29	3.93013
4.5	10.8	2.56	4.21875
5	11.94	2.75	4.34182
5.5	12.13	2.99	4.05686
6	8.19	3.39	2.41593

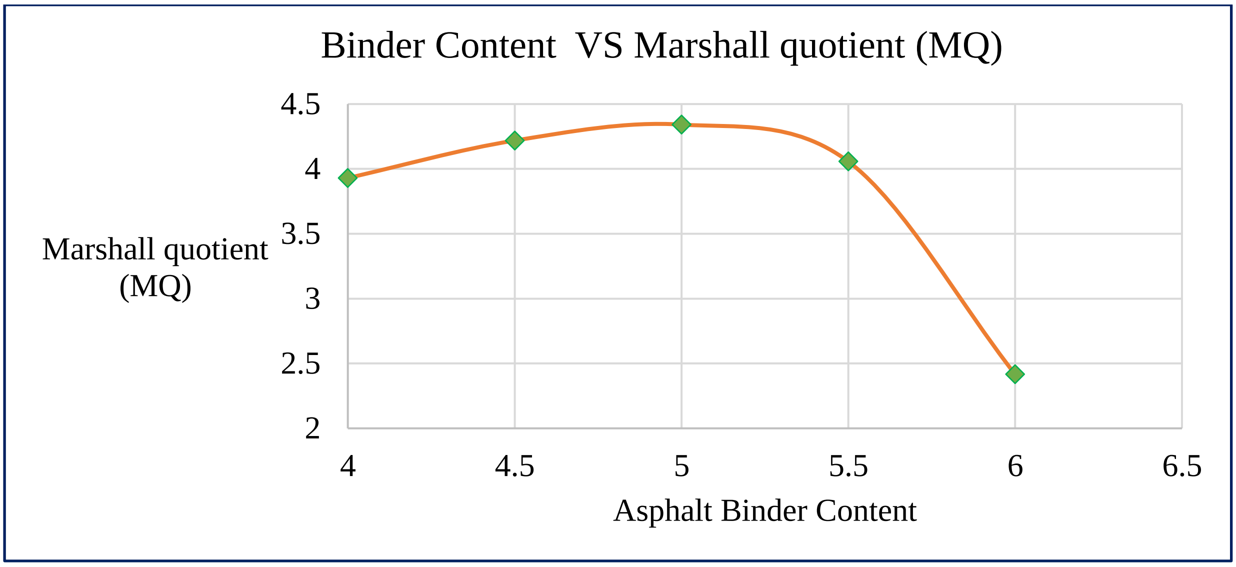


Figure 4.8 Marshall quotient for different % of Binder content

4.7 Effect of Adding PET on CR modified binder Mixture

Three Marshall specimens at each percentage of PET (0%, 2%, 4%, and 6%) are prepared and tested, which resulted in a total of 12 specimens were prepared at OBC (5.5%) to evaluate the effect of adding PET additive as filler to crumb rubber modified asphalt mixture. Marshall properties (Stability, Flow, unit weight, AV percent, VMA percent and VFB percent) are computed for modified specimens with PET.

The results of modified Marshall properties are presented as relationships between (Stability, Flow, unit weight, AV%, VMA% and VFB%). The percentages PET used are 0, 2, 4, and 6% by total weight of crushed stone natural filler in the modified asphalt binder with 10% of crumb rubber by weight of optimum binder content (5.5%).

Relationship between Stability and PET content

Modified asphalt mixtures have a better level of stability than conventional asphalt mixtures. As can be seen, the marshal stability of all asphalt mixtures containing 10% crumb rubber modified asphalt mixture with varying percentages of filler PET particles is higher than that of the mixture lacking crumb rubber and PET polymers.

The highest Marshall stability was 12.38kN, is associated with the mixture containing 2% of filler PET particles. Figure 4.9 and Table 4.8 illustrates that as the PET content increases, the stability of modified asphalt mix increases until it reaches a peak at 2% PET content, after which it begins to drop abruptly at higher PET content. This is may be due to the penetration fine particles in to mixture voids which results dense volume. The new mix resists the applied load and seems to increase stability. The modified asphalt mixture with 10% CR and 2% PET become higher stability than without PET and it increase by 9.94%. The reason behind that fine PET particle can be well distributed in the mixture and fill the voids, and increase the stiffness and also those fine PET particles have lower melting rate, resulting in more remaining of the crystalline part and increase the stiffness. This theory also proved by H. Taherkhani and M. R. Arshadi on their research investigate the effect of fine PET and Course PET on asphalt mixture. The researchers also stated that fine PET particle has more stability than the course PET particle in the asphalt mixture [42]. Therefore, it can conclude that the improvement of stability in PET and crumb rubber modified asphalt mixes can be explained as a result of the better adhesion developed between bitumen and PET as filler aggregate due to intermolecular bonding, these intermolecular attractions enhanced strength of asphalt mix, which in turn help to enhance durability and stability of the asphalt mix.

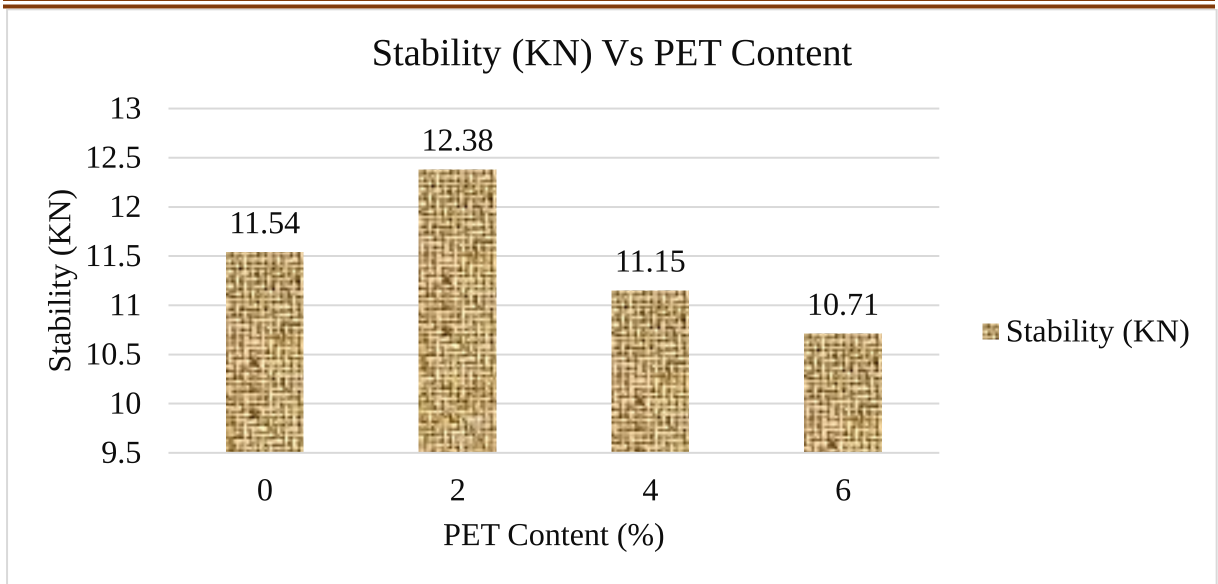


Figure 4.9 Stability (KN) Vs PET Content

Relationship between flow and PET content

Generally, the flow of modified asphalt mix is higher than the conventional asphalt mix in some extent. Table 4.8 and Figure 4.10 shows that the flow lowering continuously as the PET modifier content increase. The flow value from 2.6mm (0% PET) till it reach 2.2mm at PET content 6% of PET). The high flow values in the accepted range which indicate that the modified asphalt mixture have high flexibility which increases the ability of HMA pavement to deform without cracking.

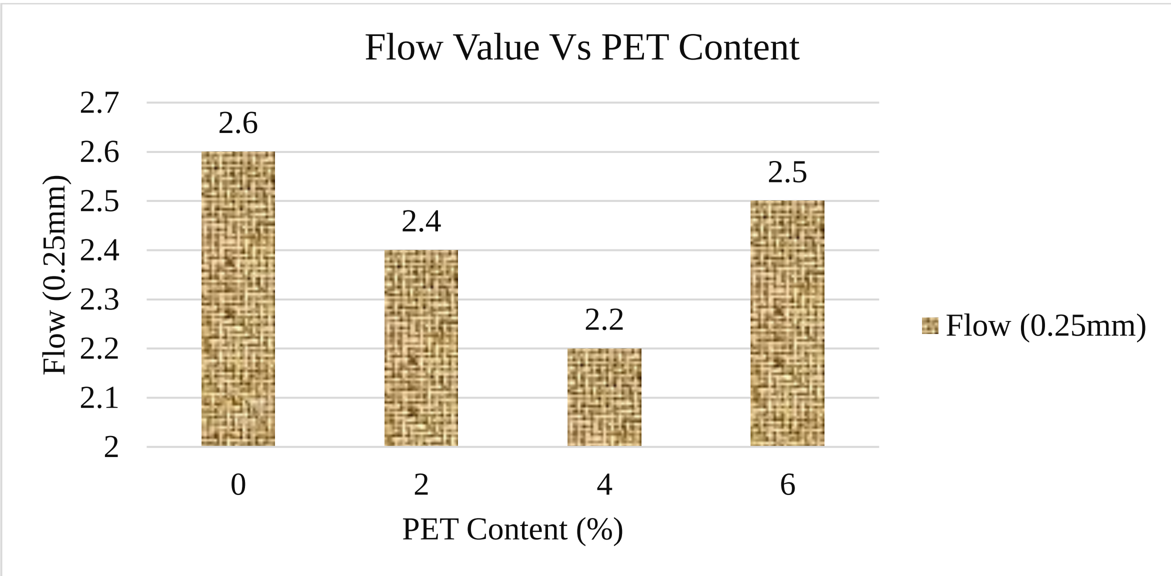


Figure 4.10 Flow Value Vs PET Content

Relationship between bulk density and PET content

PET and crumb rubber modified asphalt mix has a lower bulk density than conventional asphalt mix. The bulk density falls as the PET content increases, according to the general tendency. At 2% PET content, the highest bulk density is (2.305 g/cm3), whereas the minimum bulk density is (2.267 g/cm3) (0% PET). The low density of the added plastic material can be attributed to the decrease in bulk density. The presence of micro fine particles (PET) in the HMA causes the mix to be denser than the control mix, resulting in an increase in unit weight. Figure 4.11 and Table 4.8 depicts the relationship between asphalt mix bulk density and PET content.

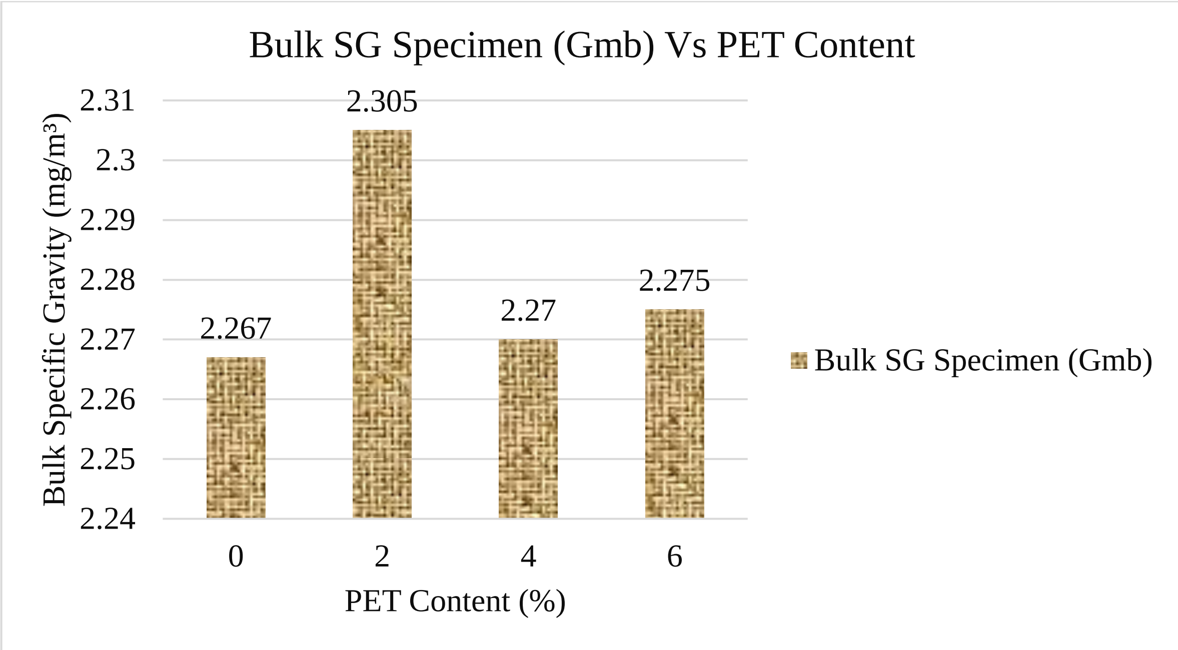


Figure 4.11Bulk SG Specimen (Gmb) Vs PET Content

Relationship between air voids (Va) and PET content

In general, modified asphalt mixes have a higher proportion of air voids than conventional asphalt mixes (5.5 percent). The Va percent of modified asphalt mixes rises gradually as the PET component rises, reaching its highest Va percent value at 6% PET. Va percent content in modified asphalt mixes is usually within standards. Figure 4.12 and Table 4.8 depicts the relationship between asphalt mix air voids and PET content.

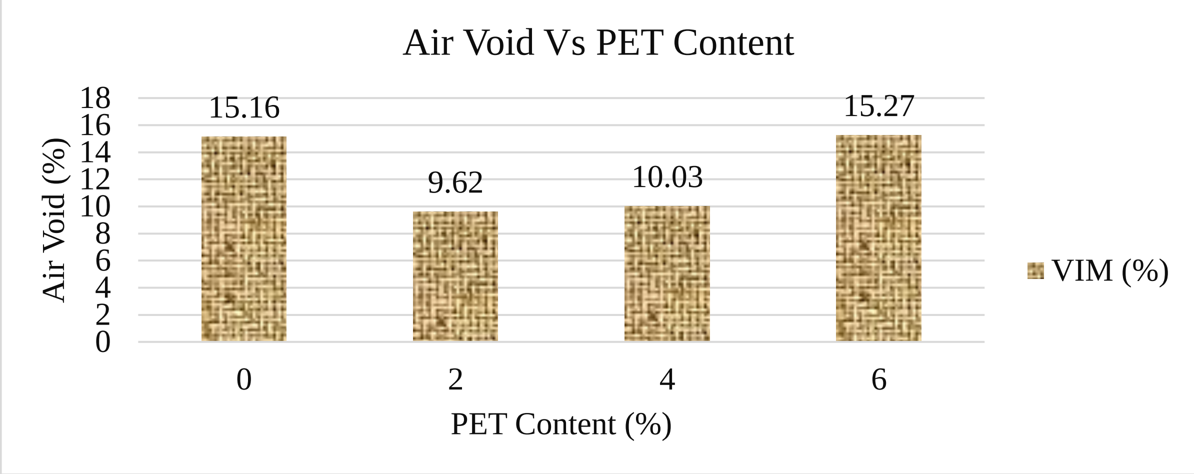


Figure 4.12 Air Void Vs PET Content

Relationship between Voids in Mineral Aggregates (VMA) and PET content

Air voids in asphalt mix Va and voids filled with bitumen Vb effect the voids in mineral aggregates percentage VMA percent for asphalt mix. In general, the VMA percent of modified asphalt mixes is higher than that of normal asphalt mixes (16.48 percent) until it reaches maximum. As the PET concentration increases, the VMA percent of modified asphalt mixes increases, reaching (16.37 percent) at PET content (4 percent). Figure 4.13 and Table 4.8 depicts the link between asphalt mix VMA percent and PET concentration.

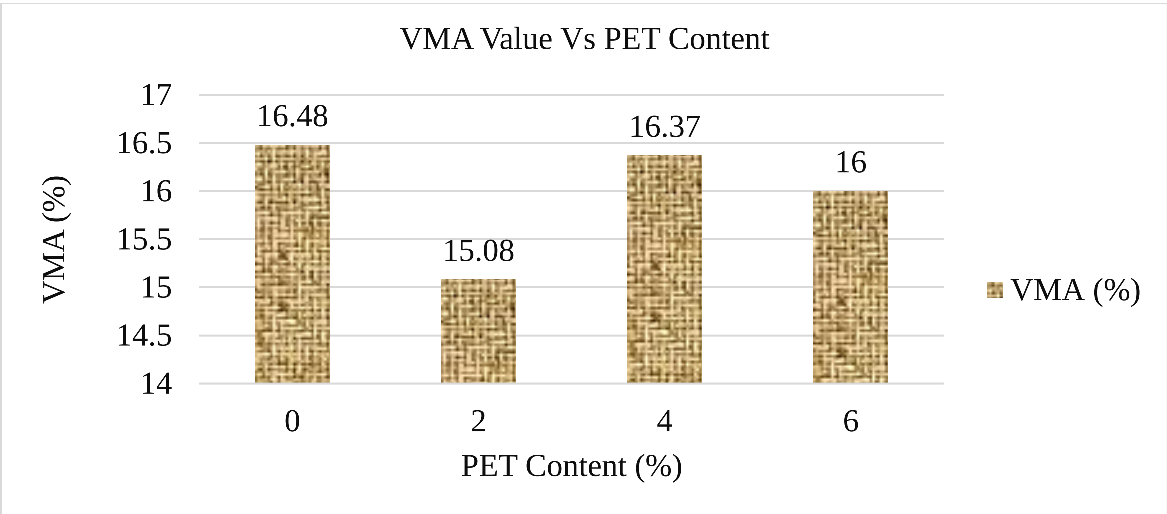


Figure 4.13 VMA Value Vs PET Content

Relationship between Voids filled with bitumen (VFB) and PET content

The maximum value of VFB percent is attained at 4% PET, as illustrated in Figure 4.14 and Table 4.8 The lowest value of VFB percent, on the other hand, is found at 6% PET. 6% of PET modified mixture have the capacity to resist more plastic deformation. In addition, it increases stiffens than other.

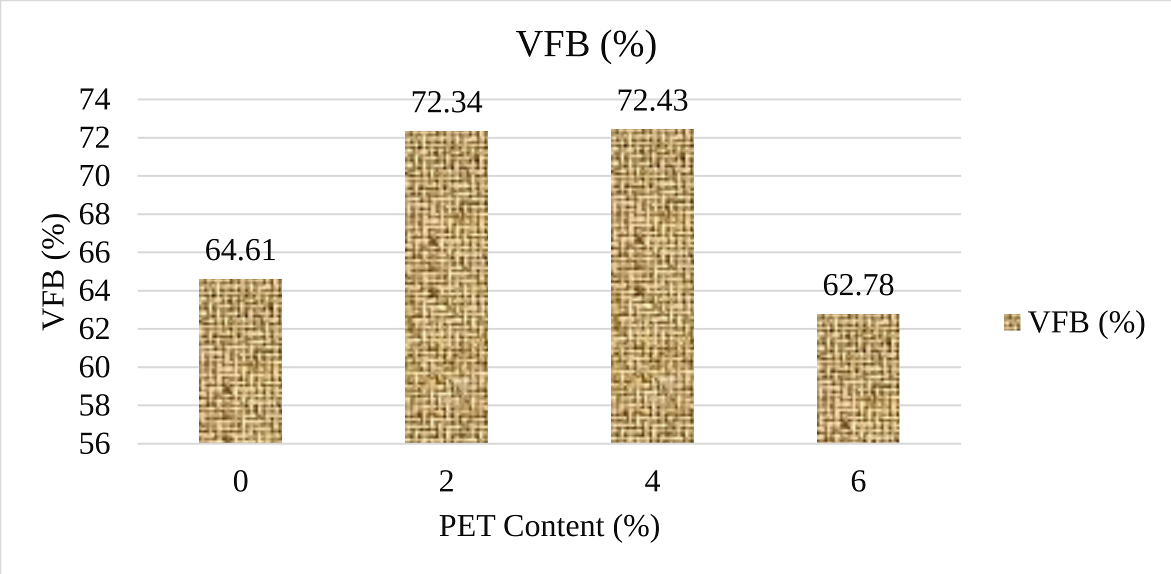


Figure 4.14 VFB Value Vs PET Content

Table 4.8 Summary of volumetric and Marshal data for Modified asphalt mixture

Bitumen content (%)	Crumb Rubber (%)	PET	Bulk SG Specimen (Gmb)	VIM (%)	VMA (%)	VFB (%)	Stability (KN)	Flow (0.25mm)
5.5	10	0	2.267	15.16	16.48	64.61	11.54	2.58
5.5	10	2	2.305	9.62	15.08	72.34	12.38	2.39
5.5	10	4	2.27	10.03	16.37	72.43	11.15	2.21
5.5	10	6	2.275	15.27	16	62.78	10.71	2.54

Figure 4.15 Shows the variation of Marshall quotient with PET content for the mixtures contain crumb rubber modified asphalt binder. the MQ increase with increasing PET content. The highest MQ is achieved by addition of 2% PET. The asphalt mixture contains 10% crumb rubber modified asphalt binder and 2% PET as filler has less permanent deformation. It can conclude that 10% CR by weight of bitumen and 2% PET by weight of filler content have good resistance on plastic deformation and have higher stiffens than other.

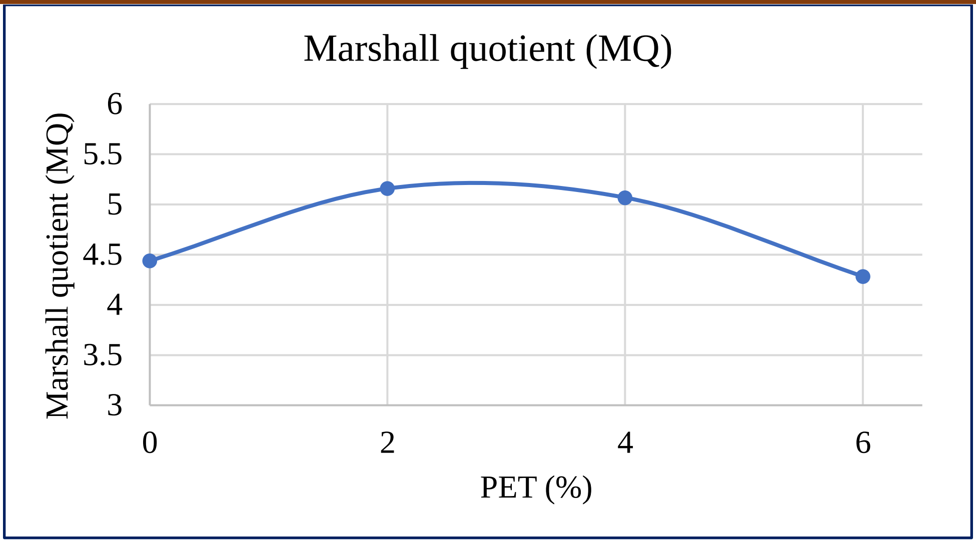


Figure 4.15 PET VS Marshall Quotient

S. S. Shinde et.al study the effect of crumb rubber in bitumen using Marshall stability test and they found that the modified asphalt mixture with 20 % crumb rubber and an OBC of 4% gives the Marshall stability value of 1181.51 kg [70] but the combination uses of crumb rubber and PET polymer in this study increase the marshal stability by 4.6%.

4.8 Optimum Polymer Content

To acquire the optimum modifier level that produce an asphalt mix with the best mechanical properties. PET percentages that satisfy higher stability was taken as optimum PET content by natural filler content weight is 2%.

4.9 Comparison of control mix with PET and crumb rubber modified mix

A comparison of the mechanical properties of PET and crumb rubber modified asphalt mix at the optimum PET content (2 % by natural filler crushed stone weight) and at the optimum Crumb rubber (10% by OBC weight).

The modified asphalt mix has higher stability and stiffness than the conventional asphalt mix (2 percent PET by natural crashed stone by weight and 10% crumb rubber by OBC weight), while the other attributes of the modified mix are still within the requirements' allowable range. The adjusted asphalt mix has a slight increase in flow and air voids, although the VMA percent and bulk density of the two asphalt mixes are nearly identical.

Because of better adhesion between crumb rubber modified asphalt binder and PET partial replacement as filler in the asphalt mixture, melted PET provides a rougher surface texture for aggregate particles in modified asphalt mix, which would improve asphalt mix engineering qualities. Improved stability would have a positive impact on the improved asphalt mix's fatigue and rutting resistance, resulting in a more durable asphalt surface.

The modified asphalt mix with 2% PET by weight of natural filler of crushed stone by weight and 10% crumb rubber by weight of OBC clearly meets the requirements of the Asphalt Institute specifications for all tested properties.

In addition, for all PET values except 6 percent PET, the stiffness values for the modified mixes are greater than those of the mixture with neat bitumen. Although the flow values have changed, the increase in stiffness is attributable to an increase in stability value. The stiffness of the PET mix is higher than that of the control mix.

Table 4.9 Comparison of Asphalt Mixtures

	Bulk SG Specimen (Gmb)	Max SG of loose mix (Gmm)	VIM (%)	VMA (%)	VFB (%)	Stability (KN)	Flow (0.25mm)
Unmodified	2.414	2.515	4.01	13.81	72.15	12.13	2.99
Modified	2.305	2.562	9.62	15.08	36.21	12.38	2.4

4.10 Tensile Strength Test

One of the most important features of asphaltic mixes is tensile strength, which is connected to fracture resistance and persistent deformation. At 25°C, the ITS of the mixes was determined. For each test condition, three specimens were used, and the average was used for analysis.

Figure 4.16 depicts the ITS value for different PET content samples. According the test result shown in the diagram, the ITS increases as PET content increases up to 2%, after which the tendency reverses and the ITS drops as PET level increases. Based on the findings, it can be stated that the ITS of mixtures containing 2% PET filler particles are higher than those of mixtures without polymers. This will enhance the moisture susceptibility and pavement resistance to fatigue cracking than other content of polymer and conventional mixture. Also, by rising the percentage of PET in the modifier from 0% to 6%, by weight of the filler content, ITS rises in the dry Condition when compared with the wet condition.

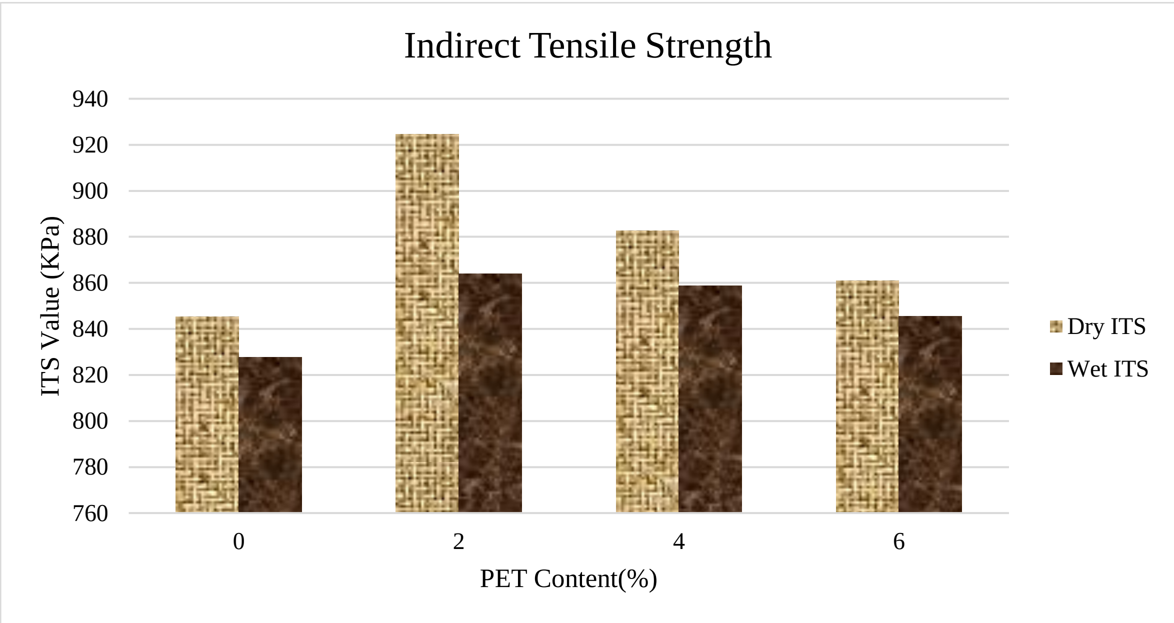


Figure 4.16 Indirect Tensile Strength

Using Equation 3.1 the tensile strength ratio was calculated for crumb rubber and PET modified asphalt mixture. Figure 4.17 shows that TSR decrease with increase PET content after the maximum TSR of 2% PET. In this research the maximum TSR belongs to specimens with 10% CR and 0% PET.

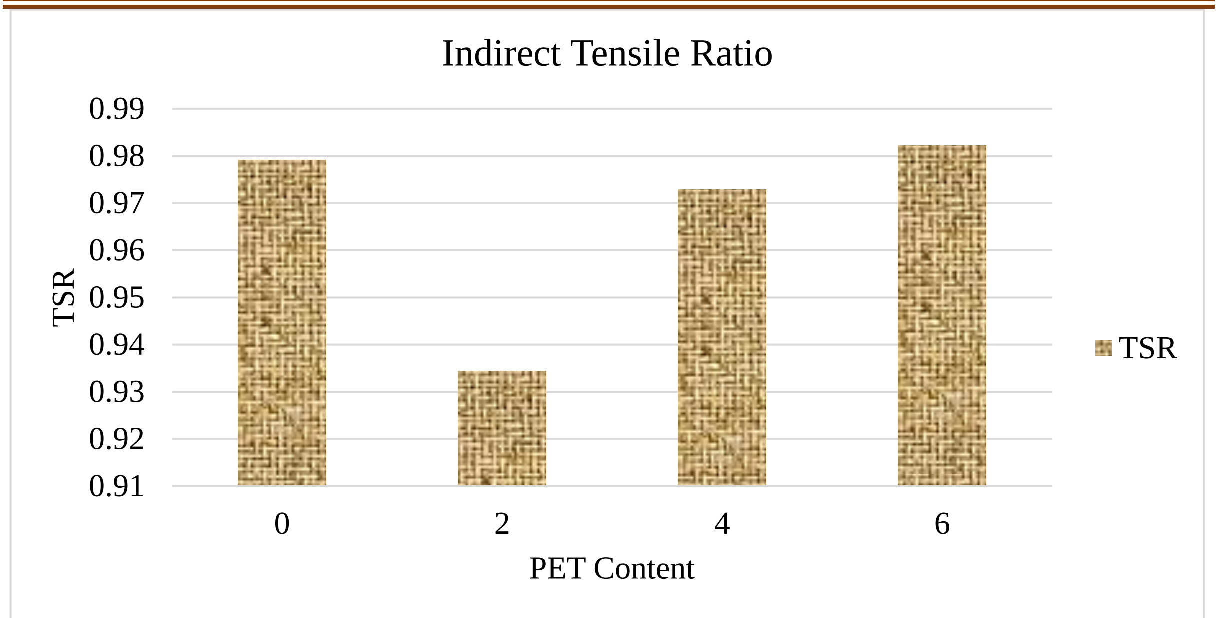


Figure 4.17 Indirect Tensile Ratio

4.11 Modulus of Elasticity of modified and unmodified asphalt mixture

Due to lack of unconfined compressive test for asphalt mixture specimen the modulus of elasticity and Poisson's ratio determined from empirical correlation based on the result of indirect tensile strength test. Table 4.10 present the calculated modulus of elasticity and the Poisson's ratio for the modified asphalt mixtures and the conventional asphalt mixture. Equation 3.3 used to calculate the compressive load subjected on the specimen based on this result the stress developed on the specimen due to the subjected load was calculated by Equation 3.4. Finally, the modulus of elasticity as shown in the figure column number four calculated by Equation 3.2. The modified asphalt mixture achieves the modulus of elasticity by about 0.53%, 4.46%, 3.45% and 3.12% (0%, 2%, 4%, and 6% PET respectively) increase compared to the control mix.

Table 4.10 Modulus of Elasticity and Passion Ratio for Asphalt Mixture

% CR	% PET	Pavement layer	Young's Modulus	Passion ratio
0	0	Asphalt	3000	0.35
10	0	Asphalt	3016.67	0.31
10	2	Asphalt	3139.24	0.32
10	4	Asphalt	3108.16	0.28
10	6	Asphalt	3098.04	0.26

4.12 Finite Element Approach Analysis

The finite element method allows structural modelling of a multi-layer pavement section having material properties that can vary both vertically and horizontally throughout the profile. Material properties of pavement layers other than asphalt surface taken from ERA pavement design manual 2013 as secondary data. Table 4.11 show the modulus of elasticity and Poisson's ratio of pavement layers for mechanistic or analysis method.

Table 4.11 Material Characteristics for Mechanistic Analysis [17]

Material	**Parameter**	**Value**	**Comment**
Granular road base	Elastic modulus	300	For all qualities with CBR> 80%
	Poisson's ratio	0.3	
Granular sub base	Elastic modulus	175	For CBR≥ 30%
	Poisson's ratio	0.3	

Subgrades	Elastic modulus		Poisson's ratio for all subgrades was assumed to be 0.4
S1		28	
S2		37	
S3		53	
S4		73	
S5		112	
S6		175	

The model based on the material properties of each pavement layers Table 4.12 shows the input parameters and material properties of pavement layer. The information gathered from AACRA (Addis Ababa city road authority) the bearing capacity of the soil around Akaki Kality sub city have a CBR value 3 and 4 due to this the subgrade class belongs to class two (S2). The modulus of elasticity for other remaining layers of pavement except surface layer their modulus of elasticity and Poisson's ratio value taken from ERA manual as stated in the previous table.

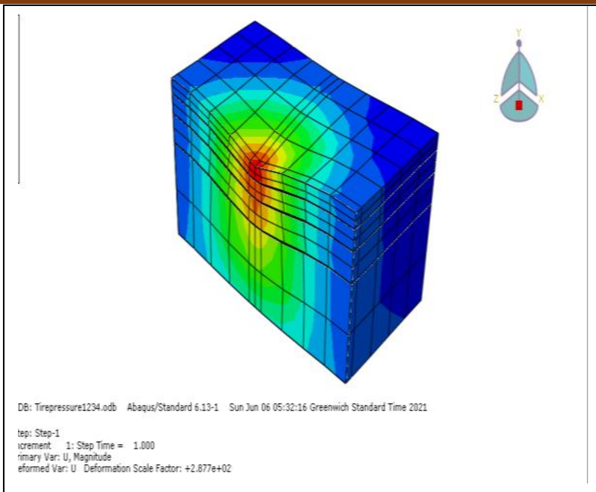
Table 4.12 Software input parameters

Pavement layer	Thickness	Modulus of elasticity	Poisson's ratio
Asphalt surface (e.g. unmodified)	5cm	3000	0.35
Base course [17]	20cm	300	0.3
Subbase course [17]	30cm	175	0.3
Sub grade [17]	1m	37	0.4

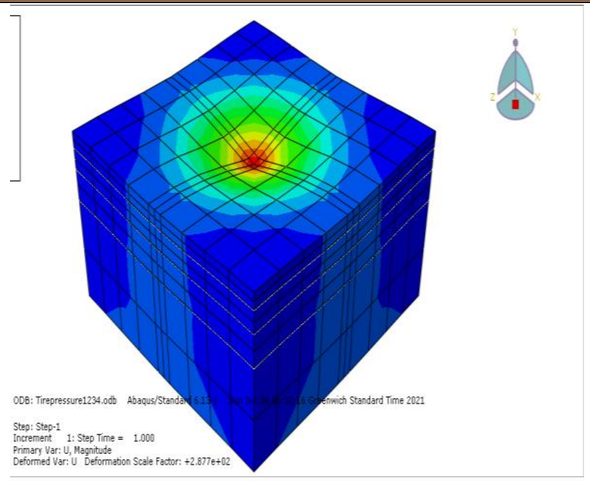
The Abaqus/CAE 6.13 Program is used to calculate the Vertical Deformation (U2) and Stress (S) for the specified pavement sections based on the results of five runs. The results are shown in the Appendix (E), which includes the results in several additional situations. These findings are divided into two categories. Vertical deformation is the first primary item, and stress is the second. The following sub-sections exemplify the discussion.

Vertical Deformation (U2) of Pavement Sections Under Different Conditions

Figure 4.18 exhibit the correlations between the changed additives and the U2. Each run of the Abaqus 6.13/CAE software results in these shapes. As stated, in the Table 4.13 depicts the vertical deformation of the pavement sections under consideration in various situations.



a. Typical section views of deformation



b. Typical 3D view of deformation

Figure 4.18 Typical Deformation of Flexible Pavement due to Tire Pressure

All of the created models examined the influence of crumb rubber and PET on the asphalt mixture by applying a constant tire pressure of 0.7 Mpa to the modified and mixture with neat bitumen.

Table 4.13 Summary of Vertical Deformation

Pavement cross section type name	Vertical Deformation(mm)
Unmodified	1.189
10% CR + 0% PET	1.179
10% CR + 2% PET	1.159
10% CR + 4% PET	1.170
10% CR + 6% PET	1.171

Figure 4.18 depicts the recorded vertical deformation values for mixture with neat bitumen and modified (i.e., 0, 2, 4, and 6% of PET value) asphalt layers with constant load pressures of 0.7Mpa in all cross sections for both unmodified and modified asphalt layers.

The vertical deformation values are 1.189mm at 0.7Mpa pressure load for using the unmodified layer when using the modified asphalt layers with crumb rubber and PET. The vertical deformation decreased to 1.179, 1.159, 1.170, and 1.171 (0, 2, 4, and 6% of the PET value) respectively. This means that the vertical deformation reduction percentages are 0.94%, 2.88%, 1.83%, and 1.73% for the modifiers respectively. It can conclude that the most active modifiers are CR and PET polymers because they reduce vertical deformations. The chemical composition of PET may cause this effect. Also, this may be due to the penetration of fine particles of PET into the mixture of voids, which results in a dense volume. Adding additives to the manufacturing surface layer to improve HMA reduces U2. The maximum reduction occurs when using 10% CR and 2% PET additive with the given constant traffic loading or tire pressure traffic loading.

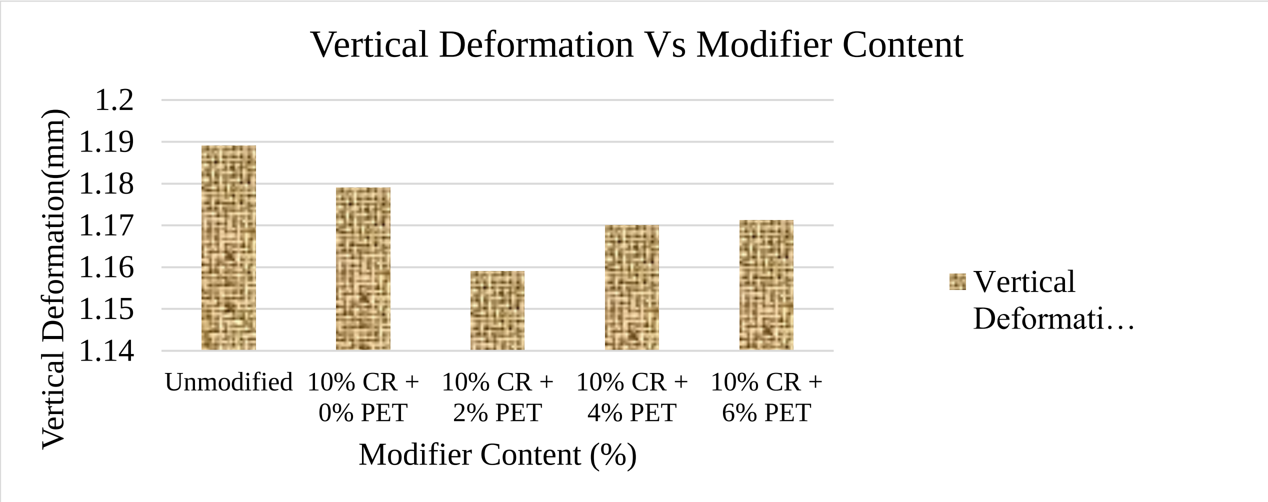


Figure 4.19 Vertical Deformation versus percentage of additives

Stress (S) of Pavement Sections Under Different Conditions

This section investigates of pavement sections effect of using the modified additives to the asphalt layer on the stress developed under the applied pressure. Figure 4.20 illustrates the typical stress distribution under applied pressure in Abaqus model.

Table *4.14* presents the typical S distribution in all section's types.

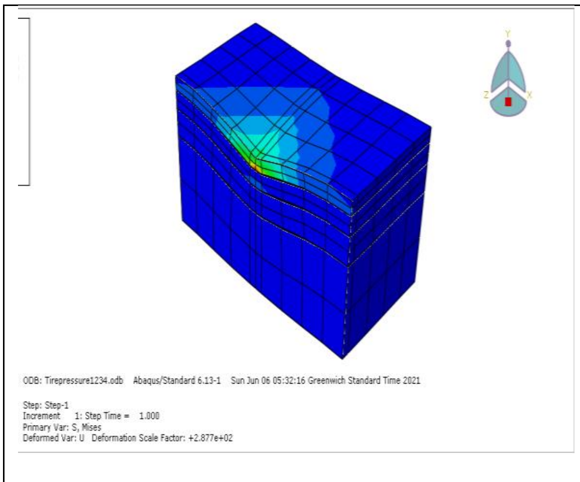
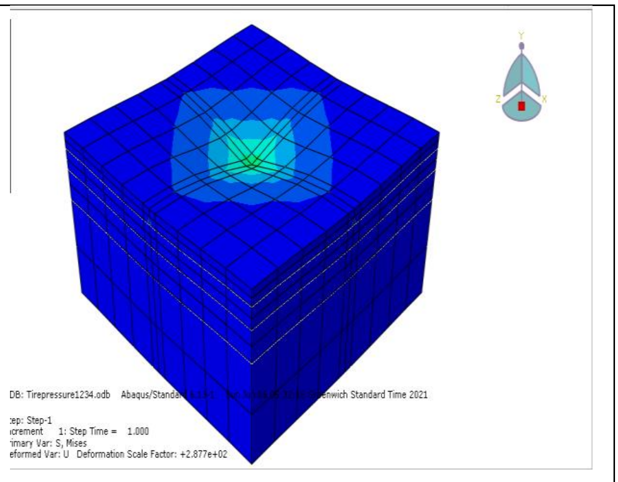
	
a. Typical section views of stress distribution	b. Typical 3D view of stress distribution

Figure 4.20 Typical Deformation of Flexible Pavement due to Tire Pressure

Table 4.14 Summary of Stress

Pavement cross section type name	Stress (Mpa)
Unmodified	0.975
10% CR + 0% PET	1.042
10% CR + 2% PET	1.046
10% CR + 4% PET	1.009
10% CR + 6% PET	0.991

Figure 4.21 shows the relationship between the stress and percentage of CR and PET on the performance of asphalt mixture for a given pavement section cross section**.** The recorded stress value is 0.975 Mpa at load 0.7Mpa for the mixture with neat bitumen layer. On the other hand, stress values were increased to 1.042, 1.046, 1.009 and 0.991Mpa for the modified asphalt layer with 0, 2, 4, and 6% of PET value respectively. This means that the S percentages were increased by 0.34%, 3.8%, 5.71% and 7.36% respectively. It is concluded that CR and PET polymers are the best modifier since it achieves the greater stiffens percentage due to developed stress.

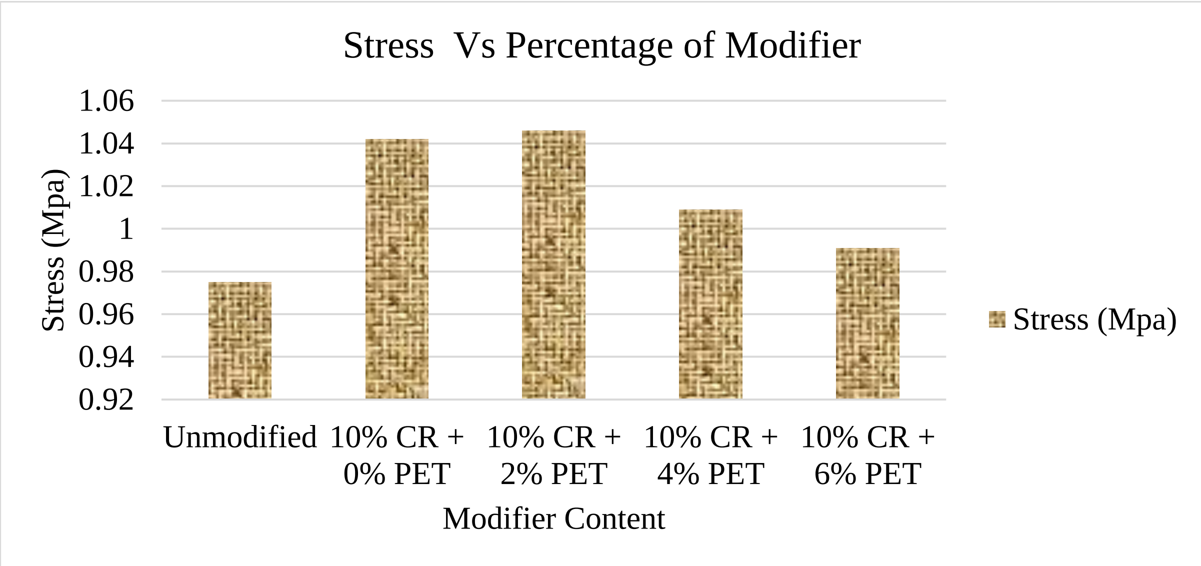


Figure 4.21 Stress versus percentage of additives

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The purpose of this study is to compare the impact of crumb rubber and polyethene terephthalate plastic polymers on the characteristics of asphalt mixtures that have not been modified. Another goal of this research is to see if the finite element method can be used to undertake stress and deformation analysis of typical pavement wearing surface layers of both modified and unmodified HMA. To accomplish this objective, a rigorously experimental program was developed and implemented. The following conclusions can be drawn based on experimental work findings for crumb rubber and PET modified asphalt mixtures compared to mixtures with neat bitumen: -

Crumb rubber modified asphalt binder test show that, as the percentage of rubber increases, penetration and ductility decrease. The rubber percentage reduced penetration, which improve rubber binder stiffness as well as asphalt binder consistency and flow resistance, resulting in improved rutting resistance.

- ❖ Aggregate materials in the asphalt mixture have good durability and resistance of both impact and gradual traffic load. Those properties of aggregate increase the strength of asphalt mixture.
- ❖ Crumb rubber can be conveniently used as a modifier for asphalt binder for sustainable management of waste tires as well as for improved performance of the asphalt binder. The optimum amount of crumb rubber to be added as an asphalt binder was found to be 10% by weight of the optimum binder content. Using a 10% CR modifier improved the bitumen's properties. It decreases the penetration value by 1.56% when compared with an unmodified asphalt binder.
- ❖ The best enhancement in HMA characteristics is achieved using 10% CR modified asphalt binder and 2% PET as a filler in the asphalt mixture. When compared to conventional HMA, it increases Marshall stability by about 0.17% and Marshall stiffness by roughly 20.71% and lowering the flow value by 20.07%.
- ❖ As the percentage of polymer in the asphalt mixture increases, the bulk density of the modified asphalt mixture with CR modified asphalt binder and PET as a filler decrease. The low density of added waste polymers can be explained as the cause of the drop-in

bulk density. The use of a CR modified asphalt binder and PET as a filler in the asphalt mixture improves the ITS value by increasing strength and reducing rutting.

- The stress created in the asphalt mixture owing to the applied tire pressure increases as the modulus of elasticity increases, resulting in a large reduction in U2. When compared to conventional and other percentages of PET, the modulus of elasticity for modified asphalt mixtures with 10% CR and 2% PET has a higher value.
- When crumb rubber and PET polymer are combined, vertical deformation is reduced by 23.65% and the percentage of stress is increased by 7.36%. By reducing deflection and increase stress, improvements in asphalt qualities (stability, flow, stiffness, Young's modulus, and Poisson's ratio) increase pavement durability.

5.2 Recommendation

a) The static loads used in this investigation are included in the modelling. Future research should include dynamic loads with a complex modulus.

b) The next researcher also studies the rutting effect of modified asphalt mixture.

c) In the future, crumb rubber and PET could be used to improve the quality of asphalt and asphalt mixtures at different temperatures, such as warm asphalt.

d) Constructing test road sections with CR and PET modified asphalt mix in order to conduct further field tests on its performance.

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APPENDIX

Appendix A: Aggregate Physical Quality Test for use in HMA

A.1 Shape Test

Table A.1.1 Aggregate Crushing Value Test

Sampled at:	Quarry site	**Source:**		Riventi Quarry
Sampling date:	15/03/2013E.C	**Visual description:**		Coarse aggregate
Tasting date:	2/4/2013E.C	**Tested by:**		Getnet M.
Material for:	Asphalt Aggregate	**Purpose:**		For research
Aggregate Crushing Value:				
Specification: BS 812: Part 110				
Observation				
Observation		**Unit**	**Trial 1**	**Trial 2**
Mass of Aggregate before test, passing 14 mm and Retain 10 mm sieve**(W_1)**		gm	3000	3000
Applied load on Specimen		KN	400	400
Time taken for corresponding Load		Min	10	10
Mass of Aggregate after compression, Retain 2.36 mm sieves**(W_2)**		gm	2551.93	2558.89
Mass of Aggregate after compression, pass 2.36 mm sieves **(W_3)**		gm	448.07	441.11
Aggregate crushing value = (W_3/W_1) *100		%	14.94	14.70
Mean Aggregate Crushing Value =		%	14.82	
Remark: 14.82 < 25 ok				

Table A.1.2 Aggregate Impact Value Test

Sampled at:	Quarry site	**Source:**	Riventi Quarry
Sampling date:	15/03/2013E.C	**Visual description:**	Coarse aggregate
Tasting date:	3/4/2013E.C	**Tested by:**	Getnet M.
Material for:	Asphalt Aggregate	**Purpose:**	For research
Aggregate Impact Value:			

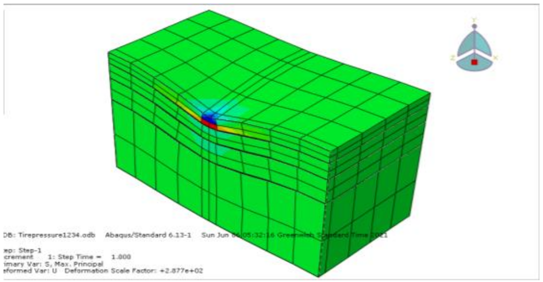
Specification: BS 812: Part 110			
Observation			
Observation	**Unit**	**Trial 1**	**Trial 2**
Mass of Aggregate before test, passing 14 mm and Retain 10 mm sieve(W_1)	gm	547.5	612.3
Mass of Aggregate after compression, Retain 2.36 mm sieves(W_2)	gm	493	546.7
Mass of Aggregate after compression, pass 2.36 mm sieves (W_3)	gm	54.5	65.6
Aggregate crushing value =(W_3/W_1) *100	%	9.95	10.71
Mean Aggregate Impact Value =	%	10.33	
Remark: 10.33 < 25 ok			

Table A.1.4 Los Angeles Abrasion (LAA) Test

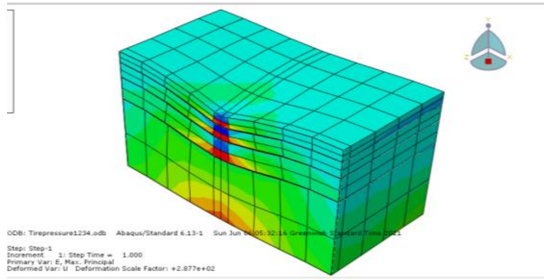
Sampled at:		Quarry site		**Source:**		Riventi Quarry
Sampling date:		15/03/2013E.C		**Visual description:**		Coarse aggregate
Tasting date:		6/4/2013E.C		**Tested by:**		Getnet M.
Material for:		Asphalt Aggregate		**Purpose:**		For research
Los Angeles Abrasion Test						
Specification: ASTM C131and C535						
Observation						
Sieve Size (Square Opening)		Mass of Indicated Size (gm)				Wt. of sample to be tested
		Grading				
Passing	Retained on	A	B	C	D	Trial 1
37.5 mm	25.0 mm	1250 ± 25	---	---	---	
25.0 mm	19.0 mm	1250 ± 25	---	---	---	
19.0 mm	12.5 mm	1250 ± 10	2500 + 10	---	---	2500

12.5 mm	9.5 mm	1250 ± 10	2500 + 10	---	---	2500
9.5 mm	6.3 mm	---	---	2500 ± 10	---	
6.3 mm	4.75 mm	---	---	2500 ± 10	---	
4.75 mm	2.36 mm	---	---	---	5000 ± 10	
Total		5000 ± 10	5000 + 10	5000 ± 10	5000 ± 10	5000
Number of Spheres Balls used		12	11	8	6	
Test Result Analysis						
Grading Type Used						
A		B		C		D
		√				
Observation					**Trial 1**	**Trial 2**
Number of Revolution					500	500
Total Wt. of Sample Tested (W)					5000	5000
Wt. of Tested Sample Retained on 1.70 mm Sieve(X)					4096	4120
Loss in grams Y = (W – X)					904	880
Percent Loss Z = (Y / W) *100					18.08	17.6
Average (%)					17.84	
Remark: 17.84> 30						

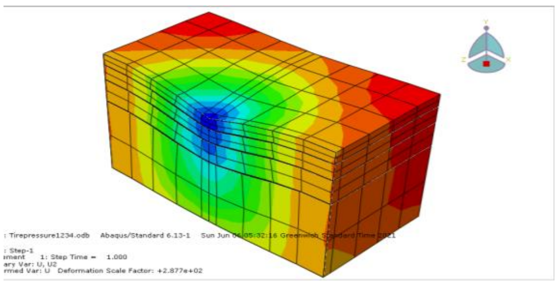
Appendix G. Summary of analysis of U2 and S of asphalt layers using Abaqus 6.13



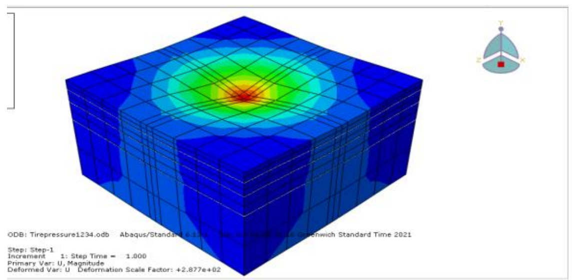
Maximum principal stress



Maximum principal strain

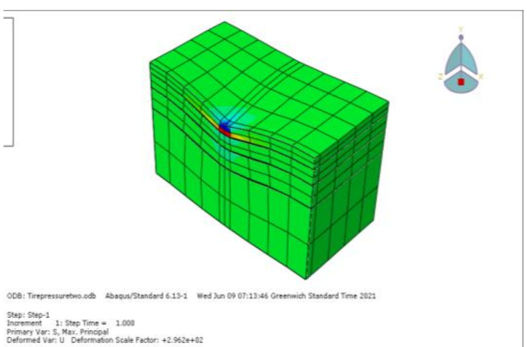


Vertical deformation along z cutting plane

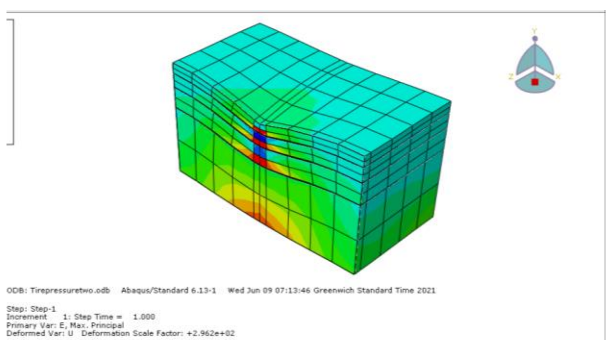


Total deformation

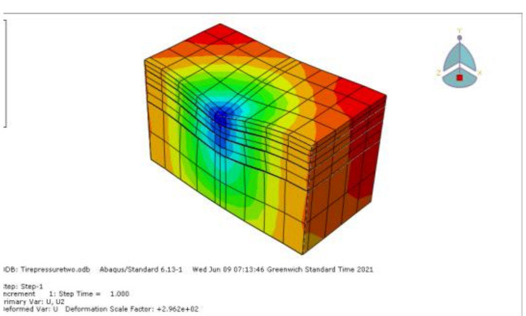
Figure G.1 Unmodified Asphalt Mixture



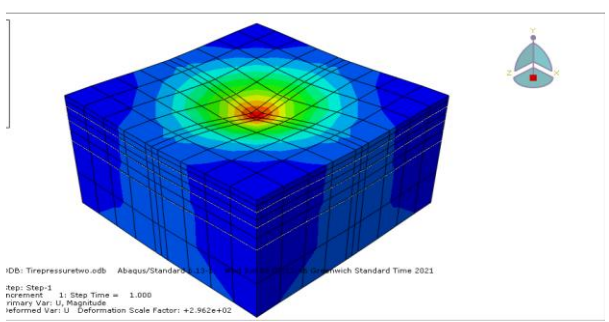
Maximum principal stress



Maximum principal strain



Vertical deformation along z cutting plane



Total deformation

Figure G.3 Modified Asphalt Mixture (10% CR And 2% PET)

Appendix H laboratory Test Pictures

Aggregate impact test

Aggregate crushing test

Sieve

Aggregate gradation

Prepared samples

Bitumen temperature

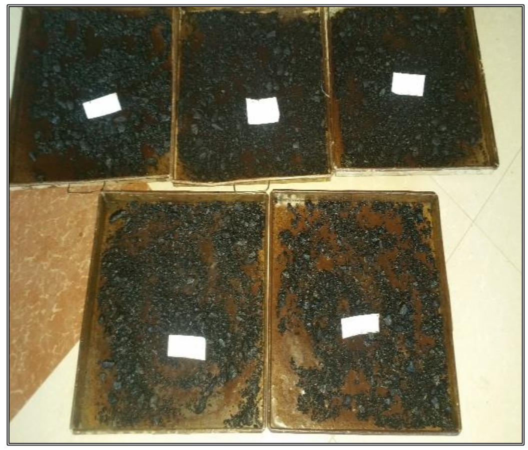
Bitumen + Aggregate

Asphalt Mixture

temperature for asphalt mixture

Casting prepared samples

Extraction of Mold



MTD

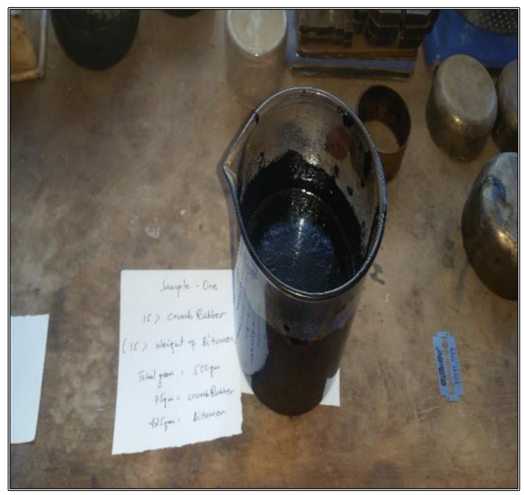
Density test

Sample prepared to stability test

Stability test

The specimen on Water Bath


Maximum theoretical density test

Prepare Modified Bitumen with Crumb Rubber

Photo credit by Getnet Mekuria

Appendix I complicate silicate chemical compostion of crumb rubber

	GEOLOGICAL SURVEY OF ETHIOPIA	**Doc.Number: GLD/F5.10.2**	**Version No: 1**
	GEOCHEMICAL LABORATORY DIRECTORATE		Page **1** of **1**
Document Title:	**Complete Silicate Analysis Report**	**Effective date:**	**May, 2017**

Issue Date: -11/02/2021

Customer Name :-Getenet Mekuria Alemu

Request No:- GLD/RQ/539/21

Report No:- GLD/RN/132/21

Sample type :- Crumb Rubber

Sample Preparation: - 200 Mesh

Date Submitted :-01/01/2021

Number of Sample:- One (01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
CR-Bihmen	12.50	2.88	6.54	<0.01	<0.01	<0.01	<0.01	0.06	0.04	<0.01	0.54	76.85

Note: - This result represent only for the sample submitted to the laboratory.

Analysts	Checked By	Approved By	Quality Control
Lidet Endeshaw	Tizita Zemene	Yohannes Getachew	Gosa Haile
Nigist Fikadu			
Habtamu Alehegn			