JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF POST GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

Experimental Investigation of Waste Plastic-Coated Aggregates for Unpaved Road Surface Treatment: A Case Study Around Jigjiga Town.

Author: Abdi Salah Nor

A research thesis submitted to the school of post graduate studies, Jimma University, Jimma Institute of Technology, in partial fulfillment of the requirements for the degree of master of science in Highway Engineering.

JULY 2024

JIMMA, ETHIOPIA

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DECLARATION

I hereby declare that the research work entitled "**Experimental Investigation of Waste Plastic-Coated Aggregates for Unpaved Road Surface Treatment: A Case Study Around Jigjiga Town"** is a genuine record of an original research work done by me under the guidance of Dr. Eng. Markos Tsegaye and Abel Tesfaye. This research work was submitted in partial fulfillment 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.

Author: Abdi Salah Nor	…………………	……/……/………
Name	Signature	Date

APPROVAL

This is to approve that the thesis prepared by **Mr. Abdi Salah Nor** entitled "**Experimental Investigation of Waste Plastic-Coated Aggregates for Unpaved Road Surface Treatment: A Case Study Around Jigjiga Town**" and submitted in fulfillment of the requirements for the degree of master of science in Highway Engineering complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

APPROVED BY BOARD OF EXAMINERS

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ABSTRACT

Most roads in Ethiopia are unpaved roads and facing rapid traffic growth as the result of rapid urbanization and industrialization leading to the packing of different industrial products like plastic bottles. Unpaved roads rapidly deteriorated due it being susceptible to various factors as its construction minimized and aggregate surfaced roads became coarser after a few years of construction. These cause dust emission problems as the fines in the surfacing material were kicked up by traffic and blown away by the wind, and fugitive dust has caused more health problems. These problems arise when there is surface material loss, which results in loss of profile and failure of the slope and profile of gravel road segments over time due to increasing traffic loads and other factors. Therefore, it is, necessary to improve the performance of unpaved roads require their pavements to be more efficient with longer life spans and utilize the waste effectively with technical development. This research was initiated to do an Experimental investigation of waste plastic and Binder coated aggregate aggregates in the construction of unpaved roads through a modified wet mix - process to enhance the desired performance of aggregate unpaved road mix and to reduce plastic bottle disposal problems. In the MWM process, bitumen was heated to a temperature of between 160 and 170 °C for 16 hours. The Polyethylene Terephthalate additive was added to the heated bitumen for the MWM process at rates of 2 % (1%B + 1%PET), 4% (2%B +2%PET), 6% (3%B + 3%PET), and 8% (4%B + 4%PET) the coated the aggregate. Polyethylene Terephthalate particles and bitumen were introduced into aggregate separately at a rate of 0%, 2%, 4%, 6%, and 8% Polyethylene Terephthalate total weight of binder (binder coated aggregate) and aggregate (Waste plastic coated aggregate). The introduction of various concentrations of Polyethylene Terephthalate from 0% to 8% of coated aggregate resulted in a decrease in flakiness index; of 22.16%, Los Angeles abrasion of 30.06%, and crushing values of 35.02% + of normal aggregate. This signifies that the strength of all characteristics' coated aggregate is greater than the strength of normal aggregate. A low Los Angeles abrasion test number is preferable since it implies less material detachment or distortion of the road material and suggests hardness. Aggregates with reduced flakiness indexes and crushing values would provide a longer service life for the road as well as more economical performance and reduce waste plastic from the landfill to minimize environmental pollution. Finally, for this matter, this study recommends different governmental (ERA and ACRA) and non-governmental organizations involved in road construction work, it is better to include such waste material input as an important improving agent in flexible pavements at a certain percentage as new finding technology on flexible pavement especially with high traffic volume.

Key words: Unpaved Road, expansive soil, waste plastic, bitumen, Gravel Road

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ABBREVIATION

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
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
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

Globally, there are many millions of kilometers of unpaved road (gravel road and earth The roads in concern are less durable than paved roads due to their loose aggregate, which causes them susceptible to gradually erosion[1],[2].

According[3] to the Federal Highway Administration (FHWA), in 2012 there were 1,357,430 miles of unpaved road in the United States, accounting for almost 35 percent of the more than 4 million miles of roadway in the Nation. However, nationally unpaved roads only account for approximately 2 percent of fatalities. Although nationally the percentage of fatalities and serious injuries are low, in some states these roadways account for up to 20 percent of the fatalities[3]. Local and rural road owners are responsible for a large proportion of these unpaved roads and need information on Strategies to enhance the safe operations on these roadways[3]. There are safety strategies that can be employed to improve safety on unpaved roads, and this document describes safety needs and treatments of unpaved roads[3].

Unpaved Roads are also an essential part of the transportation infrastructure in the majority of developing countries and cover an important aspect of the network, even in highly developed countries[4]. While in most countries, among the unpaved roads; it is the Gravel Roads, which are most popular[5]. Many unpaved roads are presently designed with very little scientific input and are constructed from the nearest available material[6]. In developing countries, unpaved roads can account for over 90 per cent of the total road network[7],[8]. In Ethiopia, unpaved roads can account for over 85 per cent of the total road network. From those, gravel road count about 30.5 percent of the total road network[9].

Ethiopia, one of the developing countries, is aware of the importance of a road network for its socio-economic development. Road infrastructure is a major area for development at present in Ethiopia, around 70% of the land area is more than 5 km away from a road that is passable in all seasons and the government is funding major construction programs to improve access throughout the year; there are also large-scale donor-assisted programs that are underway. Considering gravel roads network that was managed by both authorities, it was 82% of the country’s road network[10],[11]. There is a continuous improvement in the road network in Ethiopia. Ethiopia has 126,773 km (78,773 miles) of all-weather roads by the end of 2018, accounting for about 37% of the country's main road network. The government of Ethiopia spent 33.1 billion Birr on road construction in the fiscal year of 2017-18. During the following year, the Ethiopian Roads Authority planned to build additional 10,000 km long roads at the cost of about 41 billion Birr. From 1997 to 2018, the overall road network grew from 26,550 km to 126,773 km, with paved roads making up 40% of the road network[11]. In spite, highway pavement construction, maintenance, and rehabilitation expenditures are very expensive and challenging, especially in developing countries like Ethiopia. The country spends a large amount of its resources on the maintenance and repair of paved roads. Road, Sector Development Program achievement expenditures between 2010 and 2014 indicated that 4.3 billion Birr was spent on rehabilitation, 4.8 billion on periodic maintenance, and 700 million on regular maintenance of the flexible pavement roads[12].

According to Africa Development bank, Current Ethiopia's infrastructure performances is among the least even it compared to Sub-Saharan Africa. In this regard, Infrastructure Index puts Ethiopia at 52 out of the 53 African states. As a result, Ethiopia require infrastructure which is fit to the growing number of population as well as to bridge up with modernization and it is critical to improving unpaved performance to lower construction, maintenance, and rehabilitation costs. According to the 2019 World Bank report, the world produces 2.01 billion tons of urban solid waste per year, with at least 33% of that waste not being handled in an ecologically sound manner and is estimated to grow to 3.40 billion tons by year 2050[13]. In 2016, solid waste treatment and disposal generated 1.6 billion tons of carbon dioxide equivalent greenhouse gas emissions, primarily due to open dumping and disposal in landfills without landfill gas capture systems, which is expected to rise to 2.6 billion tons by 2050[6]. Plastic takes substantially longer to degrade than many other commonly discarded waste materials. The typical plastic water bottles, very popular in Ethiopia, need more than 450 years to degrade[14].

Unpaved roads deteriorate rapidly than a paved road because of it is susceptible to various factors as its using construction materials[2],[15].Therefore, unpaved roads should have given priority maintenance as its construction cost is minimum and maintenance cost is high[2]. The problem of Gravel surface is arising when there is surface materials loss and results in loss of profile and fail of slope and profile of gravel road segment from time to time[2]. To meet simple transportation needs by local people, unpaved rural roads are constructed by considering the natural topography using locally available gravel without having any scientific input in the form of well-defined geometric design, both length-wise and cross-wise [16],[17].

Pre-coated an aggregate surface with specified bituminous material reduces bonding problems due to the presence of dust on aggregate surfaces[18]. Good bonding can minimize the amount of windshield cracking due to dis-lodged pieces of aggregate & enhance the final quality of the pavement by preventing de-bonding b/n the binder & the aggregate[18]. Therefore, based on the critical problems and literature gap the study will be Conducted the Experimental Performance Study of Waste Plastic Bottles Containing Bitumen as Coated Aggregate for Unpaved Road Construction.

1.2. Statement of the Problem

The increased frequency of damages in the unpaved road pavement owned by the Ethiopian Road Authority and different regional Roads and city administration road authority, is draining scarce resources to maintain these damages and is creating an atmosphere of resignation in handling road projects. Currently the plastic waste management options we have in our country cannot handle all the plastic wastes generated, and the amount of the plastic waste generated is increasing. In addition, the plastic waste disposal methods have been polluting the environment and affecting human and animal lives[19]. In another area, there is much need for materials in road construction industry, for the construction of pavements one of the construction materials is binder. Bitumen is used as a binder in road pavements. This study undertakes to use the plastic waste that has been creating a big problem to our environment, in the road construction as a binder together with bitumen. The existing solid waste management system of our country not well designed[20]. From the wastes generated collected around 9% is plastic waste, from this plastic waste, large amount of its portion is water bottles (Polyethylene terephthalate PET). This waste burned in open air and dumped in land filling or incinerated for power generation. These methods have negative influence to the health of human and to the environment because of the toxic gases released. The most dangerous health effect of burning plastic is the release of Dioxin into the atmosphere. Dioxins are extremely toxic to humans and animals. They cause Cancer and hormonal birth defects that passed from generation to generation. The dioxin also ends up in the soil poisoning food for humans and animals[21],[22].

Savings in the material and cost could in return benefit the environment and financial condition of the jurisdiction that is always causes periodical maintenance and easy deterioration the surface of the road[21] As a result, excessive top size aggregate is left on the road surface as Excessive Floating Aggregate on Numerous problems stem from having excessive loose aggregate on the road surface[21]. According[21] The loose aggregate tends to accumulate outside of the wheel paths, forming ridges. The ridge pairs provide water channels that retain water[21]. Water retention is believed to be one of the major causes for distresses and failure of a gravel road[21]. Crust formed on the surface will be softened, leading to rutting and potholes[23].

Shows percentage of municipal solid waste generations by source and type in Jigjiga City[20]. It has been revealed that the largest constituent of residential solid waste is food-waste be 37 % and followed by plastic bottles & bags 28 %, papers 25 % and the remaining 6 % and 4 % are metals and cardboards, respectively. The situation is reverse in the case commercial area's waste composition as the highest constituent is cardboard 33 % and the least is food waste 7 %. However, if we see the wastes from the recycling point of view, many of the constituents are compostable and recyclable materials, and hence it indicates that recycling practices are effective SWM practice. Unfortunately, it was so far not practiced in the city, and this is why we see a lot of paper and plastic substances thrown out in river banks, ditches and open areas plate 2[20], that problems are shows those pictures in the below figures 1.1 shows the problem of waste plastic materials in the city.

Figure 1.1: The Existing Solid Waste Dumping Site of Jigjiga City Administration
(Photo by: Fisseha Adugna, August 2020)[24]

Unpaved gravel roads performance is depending on the material used; therefore, knowing the performance of the road surface material is key to the selection of road materials with long life. Gravel material for road works is a non-renewable natural resource. On unpaved roads it is used as a sacrificial layer and must be periodically replaced. Gravel roads need a constant process of reshaping and re-gravelling to uphold the necessary running surface and the acceptable degree of service. The presence of certain materials, the specific temperature conditions, and the characteristics of the terrain in Ethiopia provide considerable obstacles when it comes to carrying out this kind of maintaining them[2].

The major technical challenges for unpaved roads, as according to[2] are to provide durable and functional water crossings, surfacing with materials that provide the desired and necessary level of service, and providing effective maintenance management[2]. As stated by [23] the types of deterioration and the number of condition classes vary between different countries[2]. According to[2] the amount of dust that a gravel road produces varies greatly depending primarily on the type of surfacing material, traffic volume[2], type of vehicle, whether heavy or light, and annual precipitation in the location.

According to the research[2] the quality and type of gravel have a great effect on the amount of dust generated. When the fines are lost from a gravel surface, the stone and sand-sized particles remaining will tend to become loose on the surface, leading to some distresses like washboards and reduced skid resistance[2],[25]. In addition, excessive loose aggregate compromises the comfort and quality of the ride, impairing the safety of road users under some severe circumstances[21]. This thesis is therefore an attempt to address such issues.

The management problem of waste plastic in our urban area according[26] plastic bag waste is currently posing serious environmental and health risks all over the world – and the situation is arguably worse in developing countries like Ethiopia. This is because in Ethiopia the solid waste management system is still relatively undeveloped like other countries. Dumping plastic bags in the streets, rivers, in drains and public places is commonplace in urban areas[26] like Jigjiga and Addis Ababa.

PET bottles can be utilized in road construction projects as an eco-friendly alternative to conventional PET materials, addressing concerns regarding environmental pollution from plastic waste and the excessive use of natural resources. Recent research by various scholars [27] has explored alternative products like crumb rubber, polyethylene, polypropylene, polyvinyl chloride, ethylene-vinyl acetate, and PET for enhancing the qualities of asphalt binders and promoting environmental sustainability.

The environmental consequences of gravel roads can be significant due to dust generation and erosion[28]. In contrast, using waste plastic bottles in road construction can offer environmental benefits by reducing plastic waste and enhancing road durability[29],[30].

A comparative analysis of gravel roads with alternative materials like plastic-coated aggregates can highlight the environmental advantages of using recycled materials in road construction[31] Economically, maintaining gravel roads can be costly due to frequent maintenance needs, while using waste plastic bottles can potentially reduce long-term maintenance costs[32]. The technical feasibility of utilizing waste plastic bottles as coated aggregate for unpaved roads has shown promising results in terms of improving road properties and longevity.

Therefore, the overall objective of this study is to establish a correlation between waste plastic PET aggregate and its influence on basic aggregate quality for enhancing unpaved road construction. By examining various factors such as PET content, size, and mixing processes, this research aims to provide insights into the potential benefits of integrating PET waste in road construction projects for improved sustainability and performance and also the gap in knowledge highlights the need to investigate the effects of PET aggregate, including size, content, with modified bitumen and two different mixing processes (dry and wet mix) on the quality of basic aggregate for unpaved road surface treatment

1.3. Research Questions

This research aimed to answer the following research questions:

- What are the mechanical properties; Los Angeles Abrasion and Aggregate Crushing Value and physical properties; Flakiness Index of aggregate for using unpaved road surface treatment?
- What are the physical properties of waste plastic PET-modified binder that make it appropriate for application to unpaved road surface treatments?
- What impact does using waste plastic-modified binder and binder-coated aggregate have on the performance of unpaved road surfaces?

1.4. OBJECTIVES

1.4.1. General objective

The General objective of this study is to innovate the performance of waste plastic bottles containing bitumen as coated aggregate in unpaved road surface treatment.

1.4.2. Specific Objectives

- To determine the mechanical properties and physical properties of aggregate for unpaved road surface treatment.
- To evaluate the physical properties of a binder modified with waste plastic for use in the surface treatment of unpaved roads.
- To determine the performance of waste plastic Modified binder and Binder coated aggregate for using the unpaved road surface treatment.

1.5. Scope of research

The scope of this study was decided by its specific objectives and conducted to achieve the general objective. The study scope involves performing comprehensive assessments to determine the mechanical properties and physical properties of the composite material which is crushed aggregate, waste plastic bottles and bitumen binder, with a particular focus on durability, adverse effects on the environment and overall performance in road construction applications. It mainly focuses on evaluating the effect of using a potentially innovative PET-modified binder-coated aggregate for unpaved roads road surface treatment.

This comprehensive analysis aims to provide insights into the suitability and effectiveness of using waste plastic bottles in enhancing road quality and the scope includes an investigation into the material's resistance to environmental factors like moisture and temperature variations. By examining how the composite material responds to these conditions, the study seeks to understand its resilience and long-term viability in unpaved road construction, considering the challenges posed by different environmental elements, crucial aspect of the research scope is to determine how the performance of waste plastic modified binder and binder-coated materials influences the durability and longevity of unpaved road surfaces. By examining the broader implications of using recycled plastics in infrastructure projects, the study aims to provide insights into the sustainability aspects and potential environmental impacts of such practices.

Therefore, the scope of this study was limited to analysis mechanical and physical properties of aggregate, evaluating the consistency of binder and waste plastic for unpaved pavement type, top layer/wearing course layer and medium-density waste plastic (PET) type.

1.6. Significance of the study

Unpaved road and waste plastic causes health problems and rapidly maintenance; due to the dust-emission and waste plastic causes more problems both environmental and living things, so its need for improving the unpaved road performance and minimizing waste plastic hazards and recycling or reusing the waste plastic by mixing bitumen's for solving rapidly deterioration of the road surface. Especially improving for unpaved road surface using bitumen with mixing waste plastic and natural aggregate has a great effect due to less availability and productivity in Ethiopia. However, this study gives a significant understanding of Performance evaluation of plastic-coated aggregate for unpaved road surface. The study also contributes a significant benefit by utilizing waste and locally available natural material in engineering applications as well reducing the problem to a great extent & the cost of maintenance minimized. Moreover, this study gives some insight for future researchers around recycling waste plastic improvement by using unpaved road or road construction for minimizing the maintenance cost for reducing using bitumen and environmental impact of waste plastic.

This research is important because it aims to reduce waste plastic risks while improving the performance of unpaved roads by recycling or reusing waste plastic and adding bitumen to strengthen the road surface that is deteriorating rapidly. This study provides useful insights into the evaluation of the performance of plastic-coated aggregate for unpaved road surfaces. It also contributes to future research on improving the recycling of waste plastic through the use of unpaved roads or road construction. This method of research targets to reduce repairs and minimize the negative environmental impacts of waste plastic.

1.7 Limitation of the study

Climate variation is the main challenges during my study. Since limited representation of Ethiopia's diverse climates may restrict the applicability of findings, the study was conducting experiments in different regions with varying climate conditions to ensure the material's performance under diverse environmental factors. Collection of a varieties waste plastic is another challenge during the study, which overcome through engage in collaborations with local municipalities, construction companies, and waste management organizations to ensure access to a variety of waste plastic sources and gather diverse perspectives.

CHAPTER TWO

LITERATURE REVIEW

2.1. General and Definition

2.1.1 General

Infrastructure is crucial for evaluating agency efficiency in providing services and safety to users, productivity, cost-effectiveness, environmental protection, preservation of investment, and other operations. The challenges associated with gravel are numerous, including dust production, gravel erosion, safety risks, health hazards, discomfort, annoyance, air pollution, and road inaccessibility during the wet season. These problems arise due to traffic movement and climatic fluctuations throughout time[16].This leads to increased maintenance cost in terms of re-gravelling. Maintenance of gravel roads is expensive, especially periodic re-gravelling. To eliminate these effects and to improve the performance of the gravel roads, the best alternative is to identify the factors that affect the performance of gravel roads and recommend remedial measures to overcome the problems [16].

2.1.2 Definition

The term gravel road is generally used to refer to all unpaved roadways. A true gravel road is a roadway whose surface layer is constructed of mineral aggregate materials (such as sand, gravel, pebbles, or crushed stone) that are generally obtained from gravel pits and quarries[33]. In line with the above definition, unsealed roads as a road that has no permanent surface proofing of water in contrast of sealed road[34]. Gravel roads are built and designed to certain engineering principles, including the supply, where warranted, of gravel wearing surface[2]. Construction of these roads also involves a defined cross section, drainage, and structures (bridges, culverts)[2]. Good gravel road is constructed of three different layers. The subgrade or roadbed is the bottom layer made up of the native material (clay, silt or sand) found along the roadway alignment or fill to level a depression[35]. The aggregate base is placed on top of the subgrade and is ideally 45cm to 60cm depth. It should be constructed from free draining and easily compactable aggregate material (gravel or crushed stone) that produces a strong and stable layer. Finally, the surface layer (uniformly graded gravel or crushed stone) is placed on top of the aggregate base, and it is at least 20cm in depth. Gravel roads can also be known as unpaved roads. Great care should be taken in using gravel as a road surface in some circumstances[36]. It is unlikely that it will be suitable due to high costs of replacing the surface material that will be lost due to rainfall or traffic, or dust nuisance in the locations[37]; Where:

- Traffic is more than 200 motor vehicles per day.
- Annual Rainfall is greater than 2,000 mm.
- Longitudinal slope of road surface is more than 6%.
- Through community settlements
- The haul distance from the quarry/pit to the road site is more than 10km.
- The road section experiences flooding.
- The gravel is of poor quality.

2.2 Engineering characteristics of pavement material

The selection of pavement materials is a critical element in the design, construction, and maintenance of pavements if performance is to be optimized. Construction materials have their own characteristics suited to a specific design and construction use. “There are three basic types of soil materials used for building camp roads: gravel, sand, and fines (listed in order from largest to smallest particle size)[38]. The human eye is able to differentiate between gravel and sand particles, which are considered coarse materials[39],[40].

The pavement materials are an important component of pavement design, the selection of appropriate quality of materials for selected, sub grade, subbase, road base courses determine the capital, and whole life costs of the road, which primarily determines the performance of the road. In the selection of pavement materials guideline principles used for the material performance indication are California bearing ratio (CBR) strength, gradation, Waterberg limits (liquid limit and plasticity limit) and plasticity indexes.

2.2.1 Component of pavement structure

Major components of a pavement structures are[41]:

1. Surface course
2. Base course
3. Subbase
4. Compacted sub grade
5. Natural sub grade

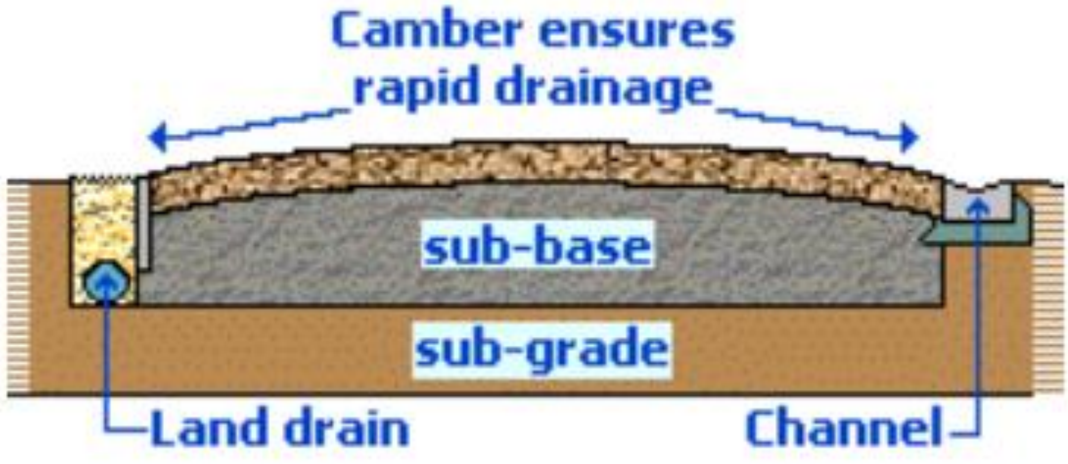

Figure 2.1 Vertical section of asphalt concrete pavement structure [41].

Bases and sub bases are usually granular materials or aggregates. The subbase which is lower in the structures does not require as high quality material as the base as loads are reduced considerably. The compacted sub grade may be the surface layer of the sub grade, compacted in cut areas, or the embankment materials in fill zones. The main function of a pavements is to reduce the high unit stress imposed by the vehicle on the surface to stress on the sub grade that are low enough to be carried without failure due to rutting, excessive settlement, or other type of distress. The magnitude of stress reduction is mainly the function of the thickness of the pavement structure.

A. Subgrade

The subgrade is the foundation of a pavement on which the vehicle load and the weight of the pavement layers finally rest.it is an in situ or a layer of selected material compacted to the desired density near the optimum moisture content. It is graded into a proper shape, properly drained, and compacted to receive the pavement layer[41].

B. Sub-base

The sub-base course is the layer of material beneath the base course. The reason that two different granular materials are used is for the economy. Instead of using the more expensive base course material for the entire layer, local and cheaper materials can be used as a sub-base course on top of the subgrade. If the base course is open graded, the sub-base course with more fines can serve as a filter between the subgrade and the base course[41]. Sometimes the sub-base course is omitted from a pavement and a relatively thick base course is placed directly on the subgrade soil.

C. Base-course

The base course is the layer of material immediately beneath the surface or binder course. It can be composed of crushed stone, crushed slag, or other untreated or stabilized materials[41]. All base course materials must have a particle size distribution and particle shape which provide high mechanical stability and should contain sufficient fines (amount of material passing the 0.425 mm sieve) to produce a dense material when compacted[11].

2.2.2 Desirable properties Gravel wearing course materials.

The performance of the gravel surface depends on material quality, the location of the road and the traffic volume using the road. Gravel roads passing through populated areas require materials that do not generate excess dust in dry weather[42]. Steep gradients place demands for gravel wearing course materials that do not became slippery in wet weather or erode easily[43]. The specified strength of the design period shall be depends on the type of pavement (Naidoo, K., 2001). Consideration should give to the type of gravel wearing course material to be used locations such as towns or steep sections. Gravel loss rates of about 25-30mm thickness a year per 100 vehicles per day is expected, depending on rainfall and materials properties particularly plasticity[43]. The materials of gravel wearing course should satisfy the following requirements that are often somewhat conflicting: a) The materials should have sufficient cohesion to prevent raveling and corrugating (especially in dry conditions) b) The number of fines (particularly plastic fines) should be limited to avoid a slippery surface under wet conditions.

The wearing course material should be durable and of consistent quality to ensure it wears evenly. The desirable characteristics of such a material are: - Good skid resistance, Smooth riding characteristics, cohesive properties, Resistance to raveling and scouring, Wet and dry stability, Low permeability, Load spreading ability. The structural failure of a pavement is associated with the strength characteristics of the constituent materials and the thickness of each layer[42]. Major failure types are surface rutting and crack formation at the top surface bottom layers. The required thickness of each layer of the pavement road varies widely depending on the materials used, magnitude and number of traffic repetitions, environmental conditions, and the desired service life of the pavement. The primary function of surface course is to provide a safe, smooth, stable riding carriageway for traffic and to contribute to the structural stability of the pavement and protect it from the natural elements perform well with in the design period of the pavement[44]. Surface gravel should meet a specification for its purpose which is to carry traffic and remain reasonably stable in wet or dry conditions[42].

Many States do not have surface gravel (aggregate) specifications. The agency needs to work with suppliers to get suitable material for surfacing. It must be acknowledged that gravel surfaces will never perform like pavements. Some loose aggregate, rutting and some corrugation may form in the best gravel when exposed to heavy traffic and prolonged wet or dry conditions[42]. Use the best material that can be obtained to improve gravel road performance[42]. Good base material needs a good percentage of larger stone for strength to carry the loads on the pavement above it. And the some needs a good percentage of fracture to help get aggregate interlock. The overall gradation is important also needs to be a good blend of sand sized particles and some fines along with the stone to get good density. But a highly plastic base material is never good. This will cause the base to hold moisture and it will lose its strength, especially during the spring thaw season. Heaving problems will become much worse as well. But the biggest problem will be early failure of the pavement surface because of weak base. Good base needs to drain well. In general, different uses require different types of material and only by testing can you really determine if it's suitable for specific purpose. Testing prior to use solves many problems that can show up later even on common gravel road. And it pays to increase your knowledge of materials and testing [42],[20]. Low-volume Road surfaces and structural sections are typically built from native materials that must support light vehicles and may have to support heavy commercial truck traffic. In addition, low-volume roads should have a surface that, when wet, will not rut, and will provide adequate traction for vehicles[44],[21]. Roadway materials, and particularly roadway surfacing materials, such as aggregate or paving, can be half the cost of a road. Selection of materials directly affects the function, structural support, rider comfort, environmental impact, and safety of the road user. Gravel surfacing material should contain the appropriate blend of material. Coarse aggregate, sand and fine aggregate parts of the surfacing material should be to their intended mix. The proper blend of different size aggregate on the road produces a surface that can be used in all types of weather[45]

From the perspective of gravel surfacing material; the material should satisfy some important criteria. The surfacing material should have sufficient cohesion to prevent raveling and corrugating (especially in dry conditions) and amount of fines (particularly plastic fines) should be limited to avoid a slippery surface under wet conditions[46],[23].

2.2.3 Typical Distresses in Gravel-Surfaced Roads

There are seven primary distress types in gravel-surfaced roads according[47]. These seven distress types are as follows:

2.2.3.1 Corrugations:

Corrugations (also known as wash boarding) are closely spaced ridges and valleys at regular intervals. The ridges are perpendicular to the traffic direction. This type of distress is usually caused by traffic and loose aggregate, especially in prolonged dry periods. These ridges usually form on hills, on curves, in areas of acceleration or deceleration, or in areas where the road is soft or potholed[47].

2.2.3.2 Dust:

The wear and tear of traffic on gravel roads will eventually loosen the larger particles from the soil binder. As traffic passes, dust clouds create a danger to trailing or passing vehicles and cause significant environmental problems[47].

2.2.3.3 Improper cross section:

A road without surface should have a crown that slopes enough from the centerline to the shoulder to allow water to drain completely off the surface. Because curves are typically banked, no crown is used there. The cross section is inadequate when the road surface is not contoured or maintained to facilitate the drainage of water into the ditches[47].

2.2.3.4 Improper roadside drainage:

Inadequate drainage results in the accumulation of water. When ditches and culverts are not in good enough form or are not properly maintained, runoff water cannot be directed and carried, which causes drainage to become an issue[47].

2.2.3.5 Loose aggregate:

Over time, the constant traffic on gravel roads will gradually expel large aggregate particles from the soil binder due to the effects of wear and tear. Aggregate on the shoulder or road surface becomes loose as a result. Loose aggregate particles are moved by traffic away from the typical wheel path, creating berms in the middle of the road or along the shoulder[47].

2.2.3.6 Potholes:

Potholes are surface depressions in the form of bowls in the road. Typically, their diameter is smaller than 1 meter (about 3 feet). Potholes are formed via the process of vehicles gradually eroding small portions of the road surface. Their growth rate accelerates as water accumulates within the cavity. The road subsequently deteriorates due to the erosion of surface material or the presence of vulnerable areas in the underlying soil[47],[39].

2.2.3.7 Ruts:

A rut is a concave depression on the surface of the road that runs parallel to the centerline of the route. Permanent deformation in the subgrade or any of the road layers is the source of ruts. They can arise from frequent vehicle crossings, particularly when the road surface is pliable. A road that has severe rutting can be destroyed. The way that gravel roads behave, how well they can drain under the combined effects of traffic and climate, and the lack of adequate care are the factors that control how quickly gravel roads deteriorate[47].

2.2.4 Engineering Characteristics of Aggregate

For the asphalt pavement, stone aggregate with specific characteristics is used for road laying. The aggregate is chosen based on its strength, porosity, and moisture absorption capacity. The aggregate was coated with waste plastic material by the following process. The waste plastics namely films, cups and foams shredded to the required size of 2.5mm – 4.36mm. The aggregate is heated to 170°C. The shredded waste plastic was sprayed over the hot aggregate. Plastics got softened and coated over the aggregate. The extent of coating was varied by using different percentage of plastics. Higher percentage of plastics was used up to 25% to evaluate the binding property, whereas lower percentage of plastics like 1% to 5% to evaluate the properties like moisture absorption and soundness.

2.2.4.1 Binding Properties

The hot plastics coated aggregates was compacted into a block using compacting machine operated hydraulically and cooled. Then the block was subjected to a compressive test using universal testing machine.

2.2.4.2 Moisture Absorption

A known quantity of plastics coated aggregate was taken. It was then immersed in water for 24hrs. Then the aggregate was dried using dry clothes and the weight was determined. The water absorbed by the aggregate was determined from the weight difference[48]. The test was repeated with plain aggregate for comparison of results.

2.2.4.3 Soundness Test

Soundness is mainly to test the stability towards weathering of the aggregates and its chemical resistance. The plain aggregate when exposed to stagnation of water, the water penetrates easily inside the pores of the aggregates. Since the water contains dissolved salts, the salt gets crystallized and expands inside the pores during evaporation resulting in the breaking of the aggregates. The low soundness property directly depends upon the amount of voids and porosity of the aggregates. This is evaluated by conducting accelerated weathering test cycle. The average loss in weight of aggregate for 5 cycles should not exceed 12 % when tested with sodium sulphate[48]. The plain aggregates and PCA were subjected to this test and the results are tabulated in for comparison.

2.2.4.4. Aggregate Impact Test

It is used to evaluate the toughness of stone or the resistance of the aggregate to fracture under repeated impacts. The aggregates were subjected to 15 blows with a hammer of weight 14kg, and the crushed aggregates were sieved on 2.26mm sieve. The aggregate impact value is the percentage of fine (passing through the 2.36mm sieve size) to the total weight of the sample. The aggregate impact value should not exceed 30% for use in wearing course of pavements. Maximum permissible values are 35% for bituminous macadam and 40 % for water bound macadam[48]. The plastic-coated aggregates were subjected to this test and the results are tabulated in.

2.2.4.5 Los Angeles Abrasion Test

The principle of Los Angeles abrasion (L.A.R) test is to find the percentage wear due to relative rubbing action between the aggregate and the steel balls used as abrasive. LAR value should be less than 30% for pavements. For the L.A. abrasion test, the portion of a plastics coated aggregate sample retained on the 1.70 mm (No. 12) sieve was placed in a large rotating drum that contains a shelf plate attached to the outer wall. A specified number of steel spheres were then placed in the machine and the drum was rotated for 500 revolutions at a speed of 30 - 33 revolutions per minute (rpm). The material was then extracted and separated into material passing the 1.70 mm (No. 12) sieve and material retained on the 1.70 mm (No. 12) sieve. The retained material (larger particles) was then weighed and compared to the original sample weight[48]. The difference in weight was reported as a percent of the original weight and called the percentage loss. LAR value should be less than 30 percent for pavements.

2.3 Plastic polymers

Polymers can be classified into two major class based on their responsive nature to heat: thermoplastic and thermos harden. The product of thermos harden polymer cannot be remolded. So, this type of polymer cannot be used as modifier of bitumen. Thermoplastic polymers are recyclable. Polymers that will be used as modifier must be Recyclable. In fact, any thermoplastic polymer can be used as modifier of bitumen if it is Compatible to bitumen. In this investigation, compatibility test is performed with waste plastic (waste polythene, PET bottle etc.) and finally waste polythene (PET) is selected as a modifier to prepare suitable blend of PMB to perform laboratory test considering the higher cost of waste PET bottle[49].

2.3.1 Types of plastics

The Society of the Plastics Industry (SPI) established a special numbered coding system in 1988 to allow consumers and recyclers to properly identify the type of resin that was used in manufacturing a product. Manufacturers follow a coding system and place an SPI code, or number, on each plastic product, which is usually molded into the bottom.

Consumer and industrial applications use these seven prominent plastic types: polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), low-density polyethylene (LDPE), and polycarbonate. Our study focuses on the specific plastic type known as polyethylene terephthalate (PET), selected for its unique properties that suit specific applications, as illustrated in the image below. This plastic material has common applications in bottles, film, food packaging, and synthetic insulation, according to the SPI Code, and our research focuses on those plastic types: polyethylene terephthalate (PET). Table 2.1 illustrates the most common types of plastics, its applications, and SPI code[34], Consumer and industrial applications use these seven prominent plastic types: polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), low-density polyethylene (LDPE), and polycarbonate. Our study focuses on the specific plastic type known as polyethylene terephthalate (PET), selected for its unique properties that suit specific applications, as illustrated in the image below. This plastic material has common applications in bottles, film, food packaging, and synthetic insulation, according to the SPI Code, and our research focuses on those plastic types: polyethylene terephthalate (PET).

Table 2.1: Types of plastics, their applications and SPI code

Plastic type	Abbreviation	Examples of applications	SPI
Polyethylene Terephthalate	PET	Soft drink and water bottles.	1 PET
High Density Polyethylene	HDPE	Cleaners and shampoo bottles, molded plastic cases.	2 HDPE
Polyvinyl Chloride	PVC or V	Pipes, fittings, credit cards, toys, electrical fittings, pens; medical disposables; etc	3 V
Low Density Polyethylene	LDPE	Grocery bags and packaging films.	4 LDPE
Polypropylene	PP	Bottle caps and closures, diapers, microwaveable meal trays, medicine and syrup bottles, also produced as fibers and filaments for carpets.	5 PP
Polystyrene	P S	Styrofoam, Take-away food containers, egg cartons, disposable cups, plastic cutlery, CD and cassette boxes.	6 PS
Other types of plastics		Any other plastics that do not fall into any of the above categories - for example polycarbonate which is Compact discs, eyeglasses, riot shields, security windows.	7 OTHER

2.4 Reduce and utilization plastic wastes in asphalt mixtures.

One of the most essential roles of scientists, engineers, researchers, and governments is to find appropriate and cost-effective methods for waste material disposal, such as recycling waste plastic. These solutions should consider not just environmental benefits, but also the reuse of solid waste resources in operations like road construction[50]. As a result, effective waste plastic recycling is one of the answers pursued by many researchers. There are several forms of waste plastic used as an asphalt pavement additive, including polyethylene terephthalate PET, LDPE, HDPE, and PET[51],[52]. The increasing number of plastic items, such as containers and bottles, consumed annually worldwide, has made disposal a serious concern. Consumers choose plastic containers because they have characteristics that make them appealing. Plastic is a strong, low-density material that is also ergonomic, durable, light, and inexpensive. Plastic is used in a variety of applications, including packaging, medical, food services and appliances, artificial implants, land/soil conservation, water desalination, flood control, housing, communication, and security. In the second half of the twentieth century, worldwide plastic usage increased from around 5 million to 100 million tons per year. As a result, in recent decades, plastic has become one of the most important solid waste elements[51].

2.4.1 Plastics as binder modifiers

At high temperatures, the asphalt binder becomes softer and less viscous, which may have an adverse effect on the asphalt mixes' permanent deformation [53],[53]. As a result, asphalt binder modification is required to improve the asphalt binder's varied engineering qualities. The use of waste plastic as a binder modifier has been the subject of several experimental studies that have shown very positive results. According to Chen et al[54], recycled PET may be beneficial in asphalt pavements, resulting in less permanent deformation of the pavement surfacing in the form of rutting. PET is widely utilized in the manufacture of water and soft drink bottles, and it is frequently recycled. The idea of employing waste PET as a polymer ingredient for binder in the asphalt mix was explored, according to the investigation's findings[55]. When compared to conventional binders, the PET-modified binder had a greater softening point, which resulted in higher resistance to permanent deformation and rutting. In the PET-modified binder, there is a loss in consistency as well as an increase in resistance to flow and temperature fluctuations. The service life of the pavement would be increased if the proper asphalt binder modifier was adopted[56],[57],[58]. The dry process is less complicated and may be used on any asphalt plant without substantial changes. This encourages the usage of this modification approach, making it easier to utilize recycled polymers[59],[60]. Another way to include plastics into the asphalt mix is to replace a portion of the mineral aggregates with a polymer of equivalent size, which is primarily used to incorporate waste plastic and consumes a higher proportion of plastic in the asphalt mix.

2.4.2 Using plastics as an aggregate coat

Coating the pavement with convectional aggregate made from waste plastics is one technique to improve the performance of the pavement and extend its service life. According to previous study[61] found that, polyethylene as one sort of polymer to enhance asphalt mixture properties. To cover mixed aggregates, ground and coarse LDPE and HDPE were used. It was observed that they improved the stability, reduced the density, and somewhat increased the air voids. Incorporating waste polymeric packaging material (WPPM) into bituminous mixes improves both pavement performance and environmental protection[62],[51].

2.4.3 Using plastics to replace aggregates

The most important component of an asphalt mixture is aggregate. It accounts for around 95% of the asphalt mix. The use of PET as a partial replacement for coarse aggregate in[61] asphalt concrete resulted in the reduction of the bulk density of the asphalt mixtures. According to [63], leftover plastics are mostly made up of LDPE pellets that are utilized to replace percentage by volume of mineral aggregates of equivalent size (2.36–5.0 mm), resulting in a new mix known as Plastic asphalt. Marshall Stability, flow, bulk density, air voids, and voids filled with binder were all evaluated when shredded plastic trash bottles were added to asphalt mixtures[64]. They discovered that coating aggregates with 8% plastic waste resulted in the best Marshall stability. With the addition of waste crushed plastic bottle content, the stability, flow, and fatigue resistance of the tested mixtures improved. Adding more plastic, on the other hand, resulted in a lower specific gravity and mixed stiffness. As a result, it becomes a long-term solution and practical option that helps to reduce plastic waste while also protecting the environment[65].

2.5. Mechanism of Plastic Blending System in asphalt

The fundamental procedures can be applied. Polymers are added to asphalt concrete mixes in three ways: dry, wet, and a third method that involves utilizing waste plastic as a partial substitution for particles of a specified size.

2.5.1 Wet Mix process

Polymers are added directly to the bitumen before combining with aggregates in the wet process, which includes mixing bitumen and waste plastic at the same time. Bitumen polymer modification, including plastic polymers, is a typical approach for improving bitumen quality by altering its rheological characteristics by mixing with synthetic polymers[66]. Bitumen modification with polymer can increase rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility in asphalt mixes. Polymer-modified bitumen has become a viable alternative to regular bitumen in a variety of paving and maintenance applications as a result of these advancements. The first approach involves adding latex polymer to bitumen, which allows for relatively simple polymer dispersion. However, the majority of published research[67],[68].

Have favored the wet procedure because it results in a greater degree of binder modification and, as a result, better utilization of recovered polymers (RP) to improve its qualities. However, some phase separation may occur if the recovered polymer modified binder (RPMB) generated by the wet method is held at high temperatures without agitation, resulting in heterogeneous bitumen that cannot be utilized to make bituminous mixes[69]. While using bitumen tanks with agitation systems or stabilizing chemicals can help with storage issues, it also raises the mix's ultimate production costs and limits the usage of the wet process[70],[71]. As a result, it is advised that this material be used only when extended periods of storage are avoided or when a recycled polymer can generate RPMB that is stable throughout storage[72].

2.5.2 Dry Mix process

The term "dry mix process" refers to any way of incorporating polymer particles directly into a hot mix asphalt mix, such as pre-blending polymer particles with heated aggregate before adding the bitumen. The polymer or modifiers act more like aggregate in the dry process, and the resulting asphalt is rubberized asphalt. Depending on the plastic qualities and mixing circumstances, this coating layer would improve the bonding and engineering properties of aggregates, resulting in an increase in the durability of asphalt mixes. Only plastic polymers are affected by the dry process[57],[73]. The dry process is less complicated and may be used on any asphalt plant without substantial changes. This encourages the usage of this modification approach, making it easier to utilize recycled polymers[59],[60]. Another way to include plastics into the asphalt mix is to replace a portion of the mineral aggregates with a polymer of equivalent size, which is primarily used to incorporate waste plastic and consumes a higher proportion of plastic in the asphalt mix.

CHAPTER THREE

MATERIAL AND METHOD

3.1 Introduction

To achieve this objective, a thoroughly experimental program was a design and implemented. The study design is shown figure it consists of two 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 materials used in the mixture include aggregate, crushed waste PET and powder and bitumen. All the above materials and the compacted specimen were subjected to various tests and conducted according to respective ERA, ASTM, AASHTO S testing standards.

3.2 Study Area

Jigjiga City is the capital and seat of the Somali Regional State and Fafan Zone. Thus, in addition to the city Administration offices, the city is a seat for all Regional Bureaus and Governmental and Non-governmental administrations at the regional level. In relative terms, it is located at about 105km (road distance) east of Harar, on the Jigjiga–Harar-Dire Dawa /AA main highway; and about 70 km west of Tog-Wuchale. The city is also located about 160km and 300km road distance from Hargeisa and Berbera port, respectively. In absolute terms, it is located at an approximate geographical coordinate of 9º20'N latitude, and 42º56’E longitudes.

The figure 3.1 Map of Jigjiga city; adopted from (Berisa and Birhanu, 2015 [74]). Red-circle indicates Jigjiga city that is study area while blue-lines represent Kebeles of Jigjiga district.

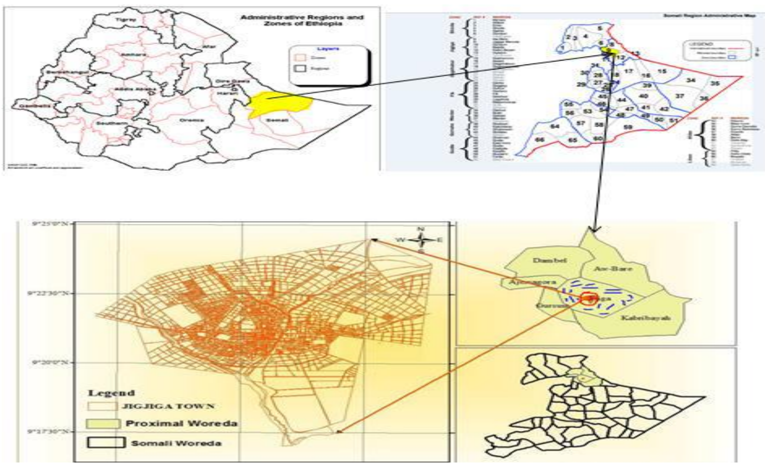

Figure 3.1 Study Area (source :-[74])

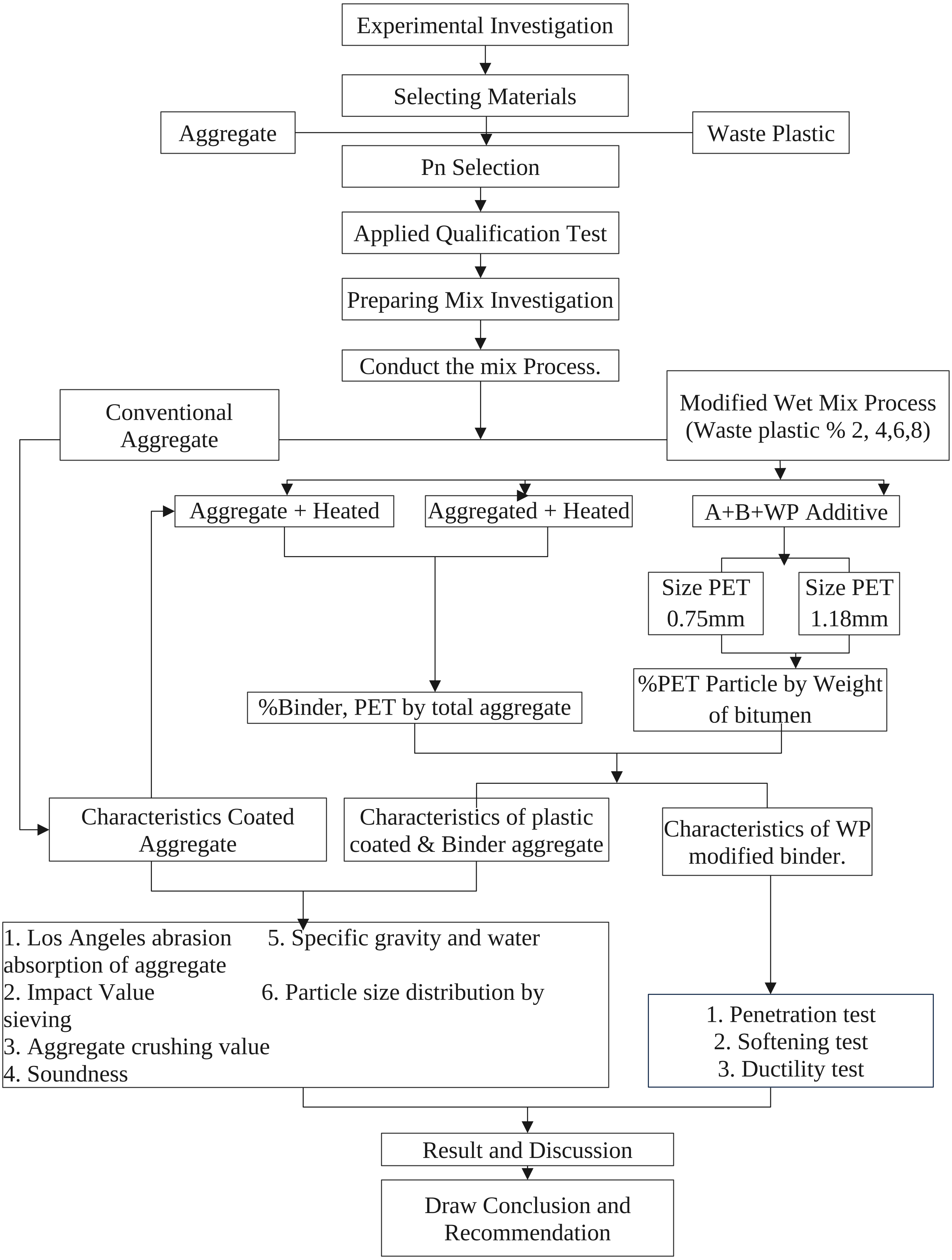

Figure 3.2: Study Design

3.3 Study Variables

3.3.1 Dependent Variable

- Performance of waste plastic bottles-containing bitumen as coated aggregate for unpaved surface road construction.

3.3.2 Independent Variable

- Physical properties of asphalt materials (Binder, Waste plastic and Aggregate).
- Content of waste plastic.
- Type of coated Liquid material (Binder, waste Plastic PET and Waste Plastic PET modified binder.

3.4 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 size 6.3mm and 9.5mm 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.

3.5 Sampling Techniques and Sampling Size

3.5.1 Sampling Techniques

The author designed the proposed sampling approach to explore the potential of using waste PET in liquid form with bitumen, a substance often used to improve the properties of gravel road surfaces. Specifically, the aim was to assess its feasibility for improving aggregate properties with coated modified polymers. The study implemented a quantitative sampling method to achieve this goal. Quantitative sampling can align with the study's objective to facilitate the collection of measurable data like physical properties, performance metrics related to waste PETs with bitumen effects on the aggregate. This method allowed for the planned collection of data and analysis of the lab test results, enabling a full assessment of the usefulness and effectiveness of mixing liquid waste PET with bitumen to treat unpaved roads. For this study, a method of purposeful sampling was used, together with a free distribution methodology, to assist the researchers in selecting a unit sample from a population.

3.5.2 Sampling Size

Many Polyethylene terephthalate (PET), High-density polyethylene (HDPE), Polyethylene (PE), Polyvinyl chloride (PVC), Polypropylene (PP), and Low-density polyethene are the five main kinds of plastic used today[75]. The most wasted of these plastics is Polyethylene Terephthalate (PET), which is primarily utilized for beverage packaging and is also used to create stiff food packaging, cleansers, oil, and other products[76],[77]. This study focused on PET waste plastic by taking the problem into account. The preparation of the sample groups non-modified or control aggregate, plastic coated aggregate, heated binder coated aggregate, and PET modified binder coated aggregate) was determined on the percentage of 0-8%, PET, and mix procedures. Wastewater bottles were processed to produce ground-up waste PET particles. Each sample group and test used three duplicate samples. Cleaning, drying, extrusion, and pelleting processes were used to create fine PET plastic with a particle size of less than 0.075mm from used polyethylene terephthalate films. Each sample group and test used three duplicate samples.

For this process are shows the figure 3.3, plastic wastes are collected and segregated into different types of plastics and shredded to a maximum size of 5mm. The shredded plastic was washed, cleaned, and dried in order to avoid any deleterious material coated with the plastic material. And it is sieved through (2.36 mm - 4.75 mm) sieve size. The same different Size aggregates (14-20, 6-14 plastic coated, 3-6 and 0-3mm), lime filler material and the same 80/100 bitumen grade has been prepared as it is used for conventional different test.

The images illustrate the step-by-step process of using shredded waste plastic in bitumen for constructing plastic roads. The method involves incorporating 0% to 8% of shredded waste plastic through a dry process into polymer-modified bitumen (PMB). In this process, the plastic-coated aggregate is formed by spraying melted plastic films onto stone aggregates, creating an oily coating. Then, the bitumen, heated to a maximum of 170°C, is added over the plastic-coated aggregate to form a mixture used in constructing unpaved road surfaces and the plastic problem in the studies areas based on those different images below this figure 3.3.

Figure 3.3: Flow diagram of plastic problem, dry method of mixing and wet mix.

3.6 PET modified Sample Preparation and Mix process Mechanism.

3.6.1 Modified Wet Mix –Process (Blending PET and Bitumen with Aggregate)

In the MWM process, bitumen was heated to a temperature of between 160 and 170 °C for 16 hours. The PET additive was added to the heated bitumen for the MWM process,

Pavement Association procedure was adopted. As per the procedure, HMA samples were prepared with varying bitumen content of to a fluid condition by heating it up to 160–170°C. Later, PET was added gradually to the heated bitumen and mixing was continued for 2 h. Later, PMB samples of 2%, 4%, 6% and 8% PET content were stored in small containers and covered with aluminum foil for later testing based on those different images below this Figure 3.4 (a and b) for mixing lab produced specimen using mechanical machine and the figure 3.5 (a and b) Modified wet mix process sample preparation and blending with bitumen.

(a) (b)

Figure 3.4**:** Mixing lab produced specimen using mechanical machine.

(a) (b)

Figure 3.5**:** Modified wet mix process sample preparation and blending with bitumen.

3.6.1.1 Plastic Modified Binder Coated Aggregate

PET particles were introduced into bitumen at a rate of 0%, 2%, 4%, 6% and 8% PET total weight of bitumen. a. Bitumen was heated first, and the temperature for CM-P was held constant at 150°C. Figure 3.6 explain that the PET polymer was added straight to the bitumen for MWM-P, and then mixed for 30-60 minutes at different temperatures of 150°C in a mixer. This images indicates the aggregate coating with modified bitumen and adding process as that show the Figure 3.6 the Plastic modified Binder sample preparation and blending with aggregate.

(a) (b)

Figure 3.6: Plastic modified Binder sample preparation and blending with aggregate.

3.6.1.2 Plastic Coated Aggregate

The aggregate is heated to 170°C degrees Celsius. We dispersed the melted waste plastic onto the high-temperature aggregate. The waste plastic material underwent a physical state change, transforming into a malleable material that served as a protective covering for the aggregate. Various amounts of polymers have modified the degree of coating. We assessed the binding capacity using a range of modified polymers, with proportions varying from 0% to 8%.

Conversely, we tested characteristics such as soundness and moisture absorption using a smaller percentage of plastics, ranging from 0% to 8%. The images in Figure 3.7 illustrate the consecutive stages of the aggregate coating process. They specifically show how polymer-modified bitumen (PMB) is added and the binder is heated thereafter. The images also demonstrate the careful monitoring of heating temperatures for sure optimum results and the mixing of plastic PET polymers.


a) Adding hot aggregate hot PMB b) After PMB coated aggregate


c) Mixing PET with binder d) checking the heating temperature

Figure 3.7: Waste plastic Coated aggregate sample preparation (a, b, c and d).

3.6.1.3 Bitumen Coated Aggregate

This technique heats the basic waste bitumen to 150°C until it becomes suitably fluid. The aggregate is heated to 170°C. We sprayed the heated waste bitumen over the hot aggregate. The bitumen started a process of softening and formed a coating over the aggregate. The coating thickness has been modified by employing different quantities of polymers. A higher percentage of plastics was used, up to 8%, to evaluate the binding property; based on those images, figure 3.8, while polymers (PMB) with lower percentages, ranging from 0% to 8%, are being examined to assess their qualities such as moisture absorption and soundness.

(a) (b)

Figure 3.8: Bitumen Coated aggregate sample preparation (a and b).

3.7. Materials

The basic components used in this research are aggregate, bitumen and waste plastic PET was description of the materials used in this stud. Generally, aggregates divided into coarse, fine, and filler fractions according to the size of particles. The following the 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

One type of conventional bitumen was selected to prepare modified bitumen as shown in Figure 3.9. For the research, Grade 80/100 of bitumen was used confirming to ASTM standards and ERA standard.

The Asphalt binder with a grade of 80/100 was used in figure 3.9.and their preparation for different test to evaluate bitumen properties number of laboratory tests such as penetration; softening point, ductility, and specific gravity have been performed. This kind of bitumen is widely used for road construction in Ethiopia.

(a) (b)

Figure 3.9: Asphalt Binder preparation (a and b)

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. 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 possessing the strength to carry and transmit the applied loads.

3.7.2.1. 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 as shown figure 3.10 in three samples. This figure 3.10 is the aggregate used for research.

Figure 3.10: Aggregate Material.

3.7.3 Polyethylene Terephthalate Plastic

The waste PET particles were acquired by crushing discarded water bottles. The Polyethylene Terephthalate (PET) plastic film undergoes a cleaning, drying, extrusion, and pelleting process to create tiny PET plastic particles with a size of less than 1.18mm and 0.075mm, as seen in Figure 3.11. Filler is a substance composed of extremely small, non-reactive mineral particles. It is added to a hot mix asphalt mixture to improve its density and strengthen it for research purposes. Polyethylene Terephthalate (PET) Modifier Waste plastic bottles were collected from local streets, highways, and public areas and sold to local recyclers by weight. The bottles were then obtained in the form of crushed pellets, with a size less than 2.36 mm (as shown in Figure 3.11). This study examines the impact of varying particle sizes of PET plastic on the alteration of asphalt mixture, as seen in Figure 3.11.

Figure 3.11: Polyethylene terephthalate plastic.

3.8 Laboratory Test Method

3.8.1 Consistency Binder Test Sequence

3.8.1.1 Penetration Test

The consistency (hardness or softness) of asphalt binder is measured by penetration test. ASTM D5 or AASHTO T 49 are the standard test methods for bituminous materials penetration. The penetration is measured in tenths of millimeters by a standard needle vertically penetrating a sample of the material under a defined load at a specified temperature during a set period. Under normal circumstances, 100 g of loading is applied for 5 s at 25 °C. Higher penetration values suggest a softer consistency, whereas lower values imply a harder bitumen. By correlating with empirical formulation, penetration test result may also be utilized as an indirect indicator of viscosity. Figure 3.12 shown that, the unmodified and PET modified sample preparation for Penetration Test and conducted the experiment in lab.

Figure 3.12: Penetrometer test

3.8.1.2 Softening Point

The softening point test technique (Ring and Ball Apparatus) is specified in ASTM D 36 or AASHTO T 53. Figure 3.13 shown that, the un- modified and PET modified sample preparation for Softening Point Test and conducted the experiment in laboratory two disks of specimens are created using shouldered brass rings to conduct the test. The rings (samples) will then be assembled and submerged in a beaker of water with a 3.5 g steel ball in the center of each ring (sample). The water will be heated at a regulated pace, generally 5 °C per minute with a 5 °C initial temperature. Finally, the softening point is calculated as the average of the temperatures observed when the two soft bitumen-encased balls contact the lower plate 25 mm below the rings. The softening point is used to categorize bitumen, assess consistency, and indicate whether the bitumen will flow at high temperatures. In hot areas, a greater softening point suggests reduced temperature vulnerability and is desirable.

Figure 3.13: Softening point ring and ball apparatus setup.

3.8.1.3. Ductility Test

The ductility of bituminous materials is measured by the distance in centimeters that the standard briquette of a bituminous sample can be stretched before the thread breaks when pulled apart at a specified speed and temperature, according to ASTM D113 or AASHTO T 51, which describes the standard test method. The standard test temperature, which will be maintained using a water bath unless otherwise specified, is 25 °C (77 °F), and the rate of draw to elongate the sample is 5 cm per minute. The ductility test assesses the adhesiveness of bitumen and its capacity to stretch the standard test that shows below figures 3.14.

Figure 3.14: Ductilimeter test setup.

3.9. Aggregate test and analysis

The aggregates used for testing were locally available and to carry out tests, these were washed under jet of water to remove dust and fine particles and they were oven dried for 24 hrs. for the purpose of setting standard results. Following Tests were conducted to investigate the properties of the aggregate:

- Los Angeles Abrasion and Aggregate Crushing Value
- Flakiness & Elongation Index (shape test) of aggregate

3.9.1. LOS ANGELES ABRASION TEST AASHTO T 96

The principle of Los Angeles abrasion (L.A.R) test is to find the percentage wear due to relative rubbing action between the aggregate and the steel balls used as abrasive. LAR value should be less than 30% for pavements. For the L.A. abrasion test, the portion of a plastics coated aggregate sample retained on the 1.70 mm (No. 12) sieve was placed in a large rotating drum that contains a shelf plate attached to the outer wall. A specified number of steel spheres were then placed in the machine and the drum was rotated for 500 revolutions at a speed of 30 -33 revolutions per minute (rpm). The material was then extracted and separated into material passing the 1.70 mm (No. 12) sieve and material retained on the 1.70 mm (No. 12) sieve. The retained material (larger particles) was then weighed and compared to the original sample weight. The difference in weight was reported as a percent of the original weight and called the percentage loss. LAR value should be less than 30 percent for pavements. Some investigators are of the opinion that Los Angeles abrasion test is more reliable for evaluating the suitability of coarse aggregates in pavements as both abrasion and impact occur during the test like the field conditions[78,79].

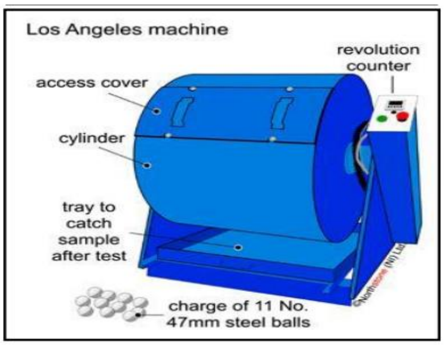

Figure 3.15: Los Angeles abrasion testing machine.

Aggregate abrasion value is determined by:

Los Angeles abrasion value (LAAV) %= $(\frac{W2}{W1})$ *100

W_2 = Weight of fines passing 1.7 mm

W_1 = Weight of the sample

3.9.2 Flakiness and Elongation Test:

The flakiness index, determined by testing in accordance with BS812, Part 105 or ASTM D 3398, shall not exceed 35. The flakiness index of aggregates is the percentage by weight of particles whose least dimension is less than (0.6) of their mean dimension. Applicable to sizes (≥) 6. 3mm.The sample is sieved through IS sieve sizes (63, 50, 40, 31.5, 25, 20, 16, 12.5, 10 and 6.3 mm). Minimum 200 pieces of each fraction to be tested are taken and weighed (W1 gm). Separate the flaky material by using the standard thickness gauge [80](IS: 2386, 1997).

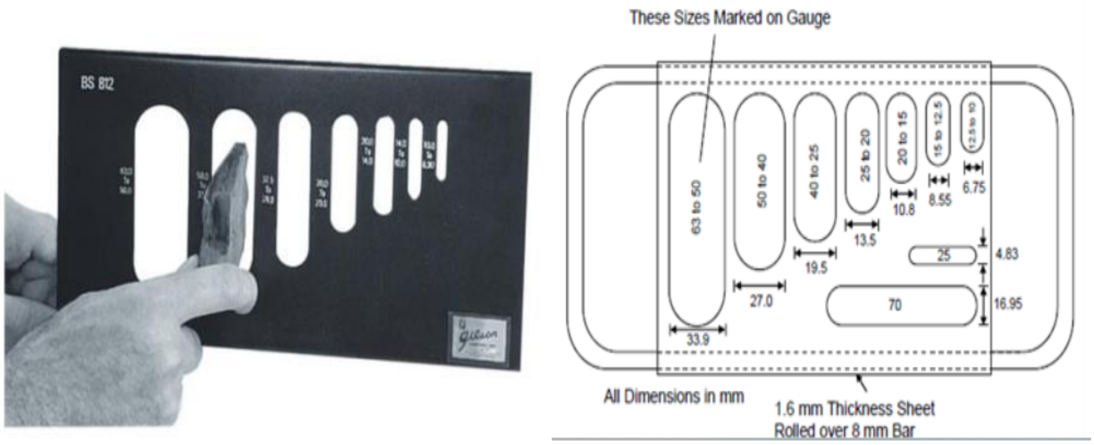

Figure 3.16: Flakiness and Elongation Testing

Flakiness index % =$(\frac{\sum W1}{\sum W2})*\mathbf{100}$

W_1= Retained weight from each sieve

W_2= Retained weight passed flakiness gauge

3.9.3 Crushing Test:

The crushing test on the normal aggregate and the plastic-coated aggregate will be carried out the basis of procedure mentioned in IS:2386, part IV- 1963., the detail procedure of which is attached in the appendix. The details of observation obtained in crushing test for both normal and coated aggregates are given below:

The resistance to crushing of coarse aggregates under gradually applied compressive load is expressed in terms of Aggregate Crushing Value. Coarse aggregates used in construction should be strong enough to resist crushing under rollers during compaction as well as due to the heavy traffic wheel loads. If the aggregates are week, the stability and performance of the pavement structure is likely to be adversely affected. The strength of coarse aggregates or the resistance to crushing of the coarse aggregates under the applied load is generally assessed by conducting aggregate test. A low aggregate crushing value indicates higher resistance to getting crushed under the application of the specified or higher crushing strength.

Figure 3.17: Aggregate crushing test machine

Aggregate Crushing value % = ($\frac{W2}{W1}$) *100

W_1= Total weight of the sample

W_2= weight of crushed aggregate

3.10. Mixing and Test procedure of Coated Aggregate

For the asphalt pavement, stone aggregate with specific characteristics is used for road laying. The aggregate is chosen based on its strength, porosity, and moisture absorption capacity. The aggregate was coated with waste plastic material by the following process.

Mixing-procedure Mixing of the ingredients (aggregates and polymers) was done by following the procedure given below:

- Required amount of aggregate has been taken in the pan.
- Then the aggregate is heated to temperature of 160°C evenly
- Weighted and shredded polythene are kept in separate container.
- Heated the Waste plastic and binder until to liquid.
- Liquid waste plastic or binder was added to the aggregate and mixed.
- Different tests such as crushing value test, Loss-Angeles's abrasion test and flakiness elongation index were carried out.
- Results were analysed and compared with that of plain aggregates.

3.10 Data processing and analysis

The research was conducted first by performing physical properties and characteristics of aggregate, bitumen, and filler material through laboratory tests. Material preparations of specimens were performed to determine the optimum bitumen and filler content through the Marshall Properties and volumetric properties of each sample. The results of the laboratory tests were analyzed using excel by drawing different kinds of graphs and tables. Then, a comparison of test results with standard specification for surface course materials on the respective ERA, AASHTO, and ASTM standards was an important aspect of analysis. Finally, the results of the analysis were present according to the research objectives.

3.11 Data quality assurances

Pre-test of the available instruments were done before the main data collection period begin and the data were collected after gaining awareness on how to collect relevant data by principal investigators. Samples were collected from appropriate sources. Standard formats were used for recording test results to prevent loss of data.

3.12 Ethical Consideration

Before starting data collection an official letter was written by Jimma institute of technology and send to Ethiopian Road Authority (ERA) and concerned local authorities to obtain the relevant sample and perform the relevant tests.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 General

This chapter explores the impact of adding waste plastic PET to aggregate and binder using different mix process mechanisms. It compares the results with conventional methods and investigates the performance of waste plastic PET modified binder, binder, and plastic-coated aggregate. The analysis consists of three parts: physical quality properties, impact of PET percentage and size on properties, performance of waste plastic and PET modified binder-coated aggregate, and comparison of mix mechanisms.

4.2 Physical Properties of Crushed aggregate, Binder, and waste plastic PET

4.2.1 Physical Properties of Crushed aggregate

The physical properties of crushed aggregate, including as particle size distribution, shape, texture, density, porosity, and specific gravity, have significant effects on its quality and effectiveness in use in construction of the road. These properties affect the workability, strength, interlocking, bonding, compactness, permeability, and weight of the aggregate, hence influencing its performance under various environmental conditions. Understanding and evaluating these properties is crucial for successful construction use. These aggregates were tested to see if they satisfied the standards of the national specification of ERA Verses the result.

The testing conducted on the aggregates listed in Table 4.1 to assess their compliance with the specification standards set by ERA. The purpose of the testing was to determine whether the aggregates met the required quality and specifications outlined in the national standards. Upon conducting the tests and comparing the results against the specification of ERA, it was observed below tables.

Table 4.1 Aggregate qualities and specification.

S/N	Test description		Test Method	Result	Specification Requirements of the Project (ERA Manual)
1	Cleanliness and Deleterious materials, %		AASHTO T176	-	<5 passing0.075mm
2	Aggregate crushing Value		BS812-110	16	<25
3	Los Angeles Abrasion		AASHTOT96	17.4	<30
4	Durability and soundness, %	Sodium test	AASHTO T104	2.65	<12%
		Magnesium test			<18%
5	Particle shape, Flakiness, %		AASHTO T176	20.3	<45%
6	Aggregate Polishing Value		AASHTO		<50%
7	Water absorption, %		ASTMC 127	1.55	<2%
8	Specific Gravity (Bulk)	i. Coarse Aggregate	AASHTOT85	2.597	-
		ii. Fine Aggregate	AASHTOT84	2.580	-
9	Affinity for Asphalt (Coating and Stripping), %		AASHTO T-182	100	>95%
10	Absorption	i. Coarse aggregate	BS812-105.2	0.750	<1%
		ii. Fine Aggregate	BS812-105.2	1.05	Max 2%

4.2.2 Physical Properties of Binder

The material based on the ERA requirement, and the results of laboratory tests. The quality and performance of asphalt mixes are determined by the physical qualities of binder asphalt cement, particularly bitumen (80-100). Below are many important physical properties and quality tests for bitumen with a grade of 80-100: ERA requirement and lab test results the physical properties of binder asphalt cement, specifically bitumen (80–100), are crucial for determining its quality and performance in asphalt mixtures. The following are some key physical properties and quality tests for bitumen (80–100):

The following are some essential bitumen (80–100) physical properties and laboratory tests: Penetration Test: Under certain conditions, this test determines the depth in tenths of a millimeter to which a standard needle penetrates the sample, giving an indication of how soft or hard the bitumen is. Test for determining the temperature at which a material becomes soft and pliable. The softening point is defined as the temperature at which bitumen softens and becomes fluid. It is a critical factor in assessing the binder's temperature sensitivity.

Ductility test: This test determines how far bitumen can stretch at a certain temperature and pull rate without breaking. It represents the binder's pliability and adaptability.

The specific gravity test measures the difference between the density of bitumen and water at a certain temperature. The test provides information on the weight and compactness of the binder. Engineers and researchers may assess bitumen's quality, consistency, and appropriateness for usage in asphalt mixes, hence ensuring the pavement structure's longevity and performance, by performing these physical property tests on bitumen (80–100).

The bitumen used in the study as asphalt binder is grade penetration 80/100 and is widely used as a base binder in Ethiopia. Bitumen properties are shown in Table 4.2 below in detail.

Table 4.2: Physical properties of waste PET.

Tests	Test Method	Specification	Results	
Penetration,100g 5sec.at 25 ℃	AASHTO T 49	80-100	86	(ERA manual, 2013)
Ductility, 5cm/Min, cm	AASHTO T 51	min, 100	100+	
Specific Gravity of Asphalt, (g/ml)	AASHTO T 228-06	1010 - 1050	1023	
Solubility in Trichlorethylene, %	AASHTO T 44	min, 99.5	99.8%	
Loss On Heating	AASHTO T 47	max, 0.2%	0.2%	
Softening Point	AASHTO T 53	45 – 52 ℃	46.0 ℃	
Flash Point	AASHTO T 48	min, 232 ℃	588.2 °F	
Water Content	AASHTO T 55	max, 0.2%	−	
Penetration of Residue	ASTM D5-IP49	min, 53	88.4	
Ductility of Residue	AASHTO T 51	min, 75	100+	

Commercially available waste PET was obtained from the Roha Pack PLC in Addis Ababa, Ethiopia. The PET was gathered, categorized based on its type and colour, cut dehydrated in an oven, and crushing into smaller pieces using the PS-900 plastic bottle crushing machine, as shown in Table 4.3.

These findings, when combined with the ASTM Standard, make it abundantly evident that several variables can affect how waste PET and regular PET compare physically. This is especially true when bitumen-containing waste plastic bottles are used as coated aggregate for the construction of unpaved road surface treatments. This table presents the lab the results based on both the Standard and the lab results:

Table 4.3: Binder laboratory results.

Property	Result	ASTM Standard
Density	0.9185 g/cm^3	D1505,792
Melting point	265 °C	D3418
Thermal conductivity	0.15 to 0.24 W m-1 K-1	
Chemical unit	(CH2-CH2-)-n	
Flexural modules	0.203 GPa	D790
Tensile strength	10.11 N/mm^3	D638

4.3 Effect of size and Content PET on Properties Binder Characteristics

4.3.1 Effect of PET Content and Size on PI Value Binder

Bitumen's performance and its sensitivity to temperature can both be improved with the use of waste plastic. The normal properties of bitumen, such as penetration, softening, and ductility, are insufficient for accurately determining the temperature sensitivity of PET-modified or unmodified bitumen. The bitumen's conformance was assessed by utilizing the PI value, which is a quantitative assessment of how the binder reacts to changes in temperatures sensitivity. The PI value can be summarized in the following way:[81].

$$PI = (1952 - 500)$$

Where Pn_{25} is penetration at 25 °C, Sp is softening point temperature (in °C) of the PET-modified and unmodified binder, and PI is penetration index with values ranging between -1 and +1. The effect of PET content and size on the PI values of bitumen are summarized in Table 4.4 below.

Table 4.4**:** Effect of PET content and size on Binder PI values.

% Of PET and Binder	Waste Plastic PET Size					
	(150 micrometer)			(75 micrometer)		
	Average Penetration @25 °C in mm	Average Softening °C	Penetration Index value B/n [−1+1] 0.1 mm	Average Penetration @25 °C in mm	Average Softening °C	Penetration Index value B/n [−1+1] 0.1 mm
0	96.0	46.0	−0.6110	96.0	46.0	−0.6110
2	95.50	47.0	−0.1550	95.50	46.70	−0.5120
4	95.0	48.0	−0.04540	95.50	47.0	−0.32350
6	92.0	50.0	0.41630	93.0	49.0	0.17350
8	85.0	56.0	1.66870	87.0	54.0	0.26920

Table 4.4 list the PI values for unmodified and modified bitumen with two sizes of waste plastic bottles (75 and 150 μm). The results indicate that an increase in the amount and size of PET caused an increase in the softening temperature and a decrease in the penetration value, resulting in a higher PI value. Effects of PET Content: As the amount of PET component increases, the PI values for modified bitumen generally show an increase compared to unmodified bitumen. Incorporating a maximum of 8% polyethylene into bitumen increases its workability and flow properties, potentially improving its effectiveness in road construction. Influence of PET Size The relationship between the size of PET and the results of PI doesn't remain constant. The penetration index (PI) values for 75 μm PET are higher than those for 150 μm PET when the PET concentrations are 2% and 4%. At concentrations of 6% and 8%, the PI values for 150 μm PET are much higher than those for 75 μm PET. The size of the PET particles may have a greater effect on the PI values as the PET content in the mixture grows, thereby altering the workability and flow characteristics. Softening temperature and penetration value The introduction of PET leads to a decrease in the softening temperature and a reduction in the penetration value due to the physical mix and blending temperature. Increases in PET size and quantity PET can be added up to 8%, which is my limit. PET content made the bitumen more rigid, leading to a decline in its penetration value. Adding PET to modified bitumen increases its temperature sensitivity and stiffness. Therefore, the bitumen indicated a rising PI value. A higher PI value shows more resistance to temperature, which leads to greater resistance to fractures and deformation induced by temperature. This makes it very perfect for construction of roads, particularly for unpaved road applications where long-term durability and stability are important.

At 25 °C, increasing the PET concentration to 8% leads to a decrease in average penetration. The data indicates that incorporating PET at a concentration of up to 8% leads to an increase in bitumen stiffness and a decrease in its penetration ability. The result has the potential to improve the bitumen's strength and resilience, making it a better choice for road construction. As the concentration of polyethylene terephthalate (PET) increases, the mean softening point also increases. In addition, increasing the amount of PET by no more than 8% improves the bitumen's capacity to withstand softening at high temperatures. This may improve bitumen's ability to withstand deformation at higher temperatures, a critical property of construction materials. The PI values demonstrate a linear correlation with the quantity of PET, ranging from -1 to 1. Polyethylene increases the plasticity index of bitumen, improving its flexibility and reducing its brittleness. This has the potential to improve the bitumen's resistance to cracking from traffic loads. The size of the waste plastic PET appears to affect the physical characteristics of bitumen. If you use the same amount of PET, bitumen with smaller particles (75 µm) tends to have less average penetration and a higher average softening point than bitumen with larger particles (150 µm). Since the p-value for the F-test is lower than 0.05, the ANOVA table indicates that the regression model is statistically significant in its capacity to explain the variance in the variable that is dependent (PI value B/n [-1 + 1] 0.1 mm with PET 75micrometet). and The F-test's p-value of less than 0.05 means that the regression model is statistically significant in explaining the variation in the dependent variable (PI value B/n [-1 + 1] 0.1 mm with PET 150 micrometer). This is shown by the ANOVA table. The mean Penetration Index value between [-1 + 1] 0.1 mm (PET 150 micrometers) was 0.25472, with a SD of 0.870755. For the penetration index value between [-1 + 1] and 0.1 mm (PET 75 micrometer), the mean was -0.20076 with a SD of 0.40036. There is a strong positive correlation between the percentage PET and binder content, as well as the PI (plasticity index) value for both PET content sizes (150 micrometer and 75 micrometer). The percentages of binders and polyethylene terephthalate (PET) and how they relate to the plasticity index (PI) value are between 0.892 and 0.966, which shows a very strong link. There is a statistically significant relationship between any combination of variables at the 0.05 level (two-tailed).

The findings show a direct relationship between the increase in the PI value and an increase in PET value and binders percentage. In summary, the results indicate a strong relationship between the percentage of polyethylene terephthalate (PET), binder content, and the plasticity index (PI) value, regardless of the amount of PET present. The correlation coefficient (R) reaches 0.932 as both the percentage of PET and binder content go up. This shows that there is a strong positive linear relationship between the size and the PI value and the percentage of PET and binder content. The coefficient of determination (R2) stands at 0.868, indicating that the percentage of PET and binder content and size accounts for approximately 86.8% of the variability in the outcome variable (PI value). The study of innovation This study examines the performance of waste plastic bottles containing bitumen as a coated aggregate for surface treatment of unpaved roads. The research relies on linear regression to determine its indications.

The study examines the influence of PET content and size on plasticity. The study demonstrates a robust and positive association between the proportion of PET and binder content and the plasticity index (PI) value. This suggests that the amount of PET and binder content is a good indicator of how flexible something is. The models demonstrate a strong fit to the data, as indicated by high R-squared values. This suggests that the percentage of PET and binder content, as well as the impact of PET content size, can account for a significant portion of the variation in the PI value. According to regression analysis, both sizes of PET content have a noticeable effect on plasticity, but the 75 micrometer PET content size has a slightly stronger effect. The increased F-value and decreased p-consequence observed in the ANOVA results for the regression model involving a PET content size of 75 micrometers serve to validate this observation. These results suggest that instead of discarding bitumen-covered plastic bottles, we could utilize them as coated aggregate to enhance unpaved roads, thereby enhancing the plastic properties of the final material.

To summarize, the regression analysis using linear regression shows that the quantity and size of waste plastic have a significant impact on the plasticity properties of bitumen-coated aggregates produced from waste plastic bottles. The effects of these findings are significant in terms of improving and maximizing road surface treatments to be more efficient and sustainability. The effect of the size and content of PET on the characteristics of asphalt binder is examined in this study.

Table 4.5 presents the impact of mixing techniques, namely wet and dry mixing, on the main empirical characteristics of PET-modified and untreated bitumen. The table includes different quantities of PET and variable sizes. The results of the dry mix experiment indicate that increasing the size of PET particles from 75 micrometers to 150 micrometers and increasing the quantity from 0% to 8% led to a drop in penetration and ductility values, while concurrently increasing the softening point. This can be related to the benefits of the dry process, which modifies the properties of the binder which functions as a lubricant, causing PET particles to improve the stiffness of bitumen (reducing penetration) and raise its softening point.

The advantage of the dry process is that it modifies the properties of the binder, acting as a lubricating agent. This modification permits Polyethylene terephthalate (PET) particles are used to improve the stiffness of bitumen, resulting in a decrease in its penetration. Additionally, the inclusion of particles made from PET raises the softening point of bitumen, which causing it to become harder. Polyethylene terephthalate (PET) is a polymer that undergoes a process of hardening when heated to temperatures over an amount of time. Therefore, it cannot be mixed with hot bitumen. The results of the MWM process, where bitumen was heated to a temperature of between 160 and 170°C, are summarized in Table 4.5. All the empirical test results remain constant and the same as the baseline bitumen.

Table 4.5 : Physical properties of asphalt binder.

% PET	Average Penetration @25 °C in mm		Average Softening °C		Ductility (cm)	
	(150micrometer)	(75micrometer)	(150micrometer)	(75micrometer)	(150Mmeter)	(75Mmeter)
0	96.0	96.0	46.0	46.0	100.0	100.0
2	95.0	95.50	48.0	47.0	89.0	90.0
4	95.0	95.50	48.0	47.0	89.0	90.0
6	92.0	93.0	50.0	49.0	85.0	85.0
8	85.0	87.0	56.0	54.0	75.0	78.0

Table 4.5 shows the impact of content and size on the fundamental characteristics of binder. The data suggests that enlarging the PET size from 75micrometer to 150micrometer and increasing the content from 0% to 8% has resulted in a decrease in penetration and ductility values, while causing an increase in the softening point. This phenomenon may be ascribed to the alteration of the binder characteristics, which function as a lubricating agent. This alteration enables PET particles to enhance the stiffness of bitumen (resulting in decreased penetration) and raise its softening point. Consequently, the augmentation of PET content and size in the base binder by a MWM process resulted in a greater softening point and reduced ductility due to decreased interlocking of PET content with the bitumen.

4.3.2 Effect of Waste Plastic PET Content on Water Moisture Absorption properties of Aggregate.

The figure 4.1 the water absorption vs. percentage of PET shows the water absorption percentage of the aggregate on the y-axis and the percentage of PET content on the x-axis. The water absorption values range from 1.5% to 0.8%. The below figures demonstrate a declining trend, with the water absorption percentage rising gradually from 0% to 8% of the total PET concentration. These graphs' tendencies indicate that adding more PET to the aggregate may have an impact on its water-absorbing qualities, which are crucial for the effectiveness of products used to treat the surface of unpaved roads.

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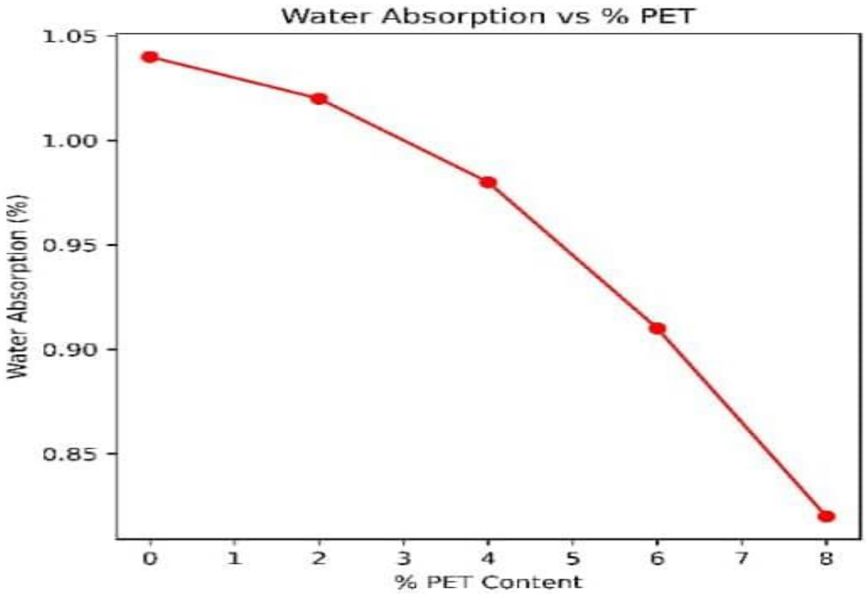

Figure 4.1: Effect of PET Content on Aggregate Moisture absorption of properties.

Figure 4.1 illustrates that the aggregate with the least amount of plastic has the highest moisture content, which is considerably reduced with the addition of plastic coating. Observe both regular aggregate and aggregate with different proportions of plastic. At 0%, 2%, and 4%, 6% and 8%, the numbers decreased from 1.5%, 1.02%, 0.98%, 0.9%, and 0.8%. The aggregate's moisture/void content is reduced by the higher plastic content. The moisture content absorbed has been improved by 46.6% when comparing traditional aggregate with aggregate with a maximum plastic component of 8%. It indicates that the sample's moisture content is decreased as permeable pores fill up.

4.3.3 Effect of Waste Plastic PET Content on Specific gravity properties of Aggregate.

Figure 4.5 shows the relationship between the specific gravity value and the plastic content. It is evident from careful observation that as the amount of plastic grows, the specific gravity similarly increases.

The specific gravity of the aggregate increases from 2.63 in the control specimen to 2.67 and 2.70, respectively. For 2%, 4%, 6%, and 8% plastic coating, the specific gravity rises to 2.72 and 2.75, respectively. The conventional aggregate has a specific gravity of 2.39, which is also good. Still, from the results, coating aggregates with plastic enhances the specific gravity because aggregates with high specific gravity provide a longer life span and durability.

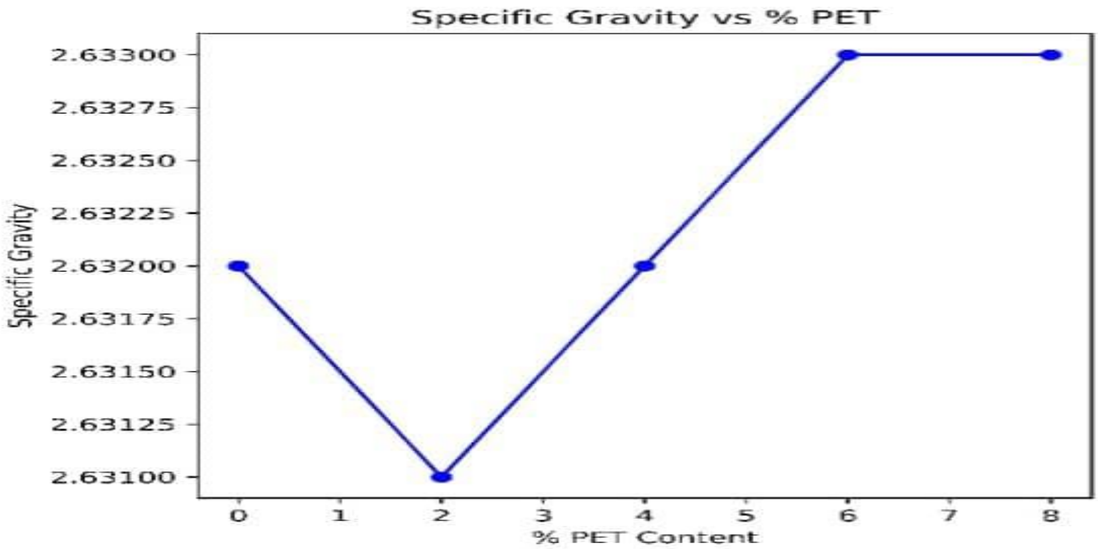

Figure 4.2: Effect of PET Content on Aggregate specific gravity of properties

The trends of data in specific gravity with respect to the percentage of PET content is visualized in the graphs that shows the relationship between the percentage of PET content and specific gravity.

Specific Gravity vs % PET Content the specific gravity remains relatively constant across different percentages of PET content, indicating that the addition of PET does not significantly affect the specific gravity of the aggregate.

The aggregate's specific gravity exhibits an initial fall as the PET concentration rises from 0% to 2%. However, it subsequently experiences a significant increase when the PET level reaches 6%. This implies that the specific gravity, which is crucial for the density and load-bearing capability of the aggregate, may be balanced within an ideal range of PET concentration.

These trends indicate that incorporating waste plastic PET into the aggregate for unpaved road surface treatment could enhance the material's performance by reducing water absorption without affecting its specific gravity.

4.4. Performance of Evaluation of waste plastic and Binder -coated Aggregate for unpaved road treatment.

4.4.1 Waste plastic Coated Aggregate

4.4.1.1 Effect of Waste Plastic PET Content on Flakiness Index properties of Aggregate

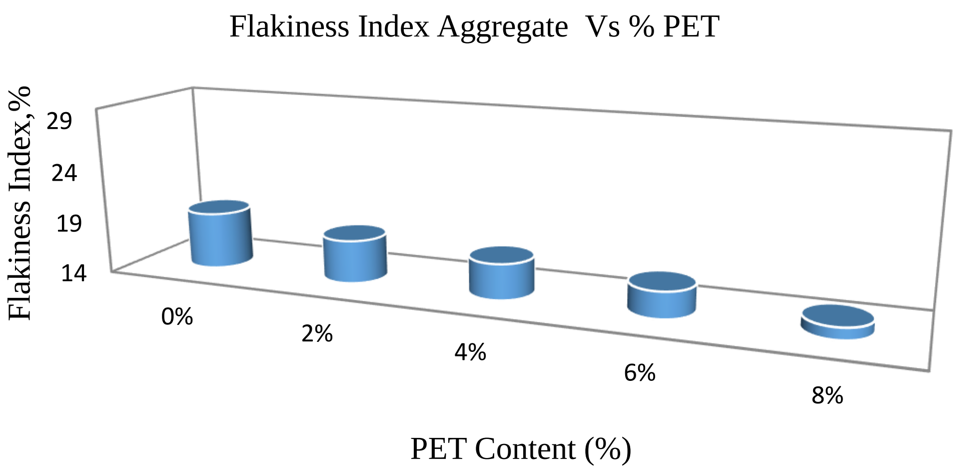

Figure 4.3: Effect of PET Content on Flakiness Index of Aggregate properties.

Figure 4.3 demonstrates the flakiness Index of properties waste plastic coated Aggregate with various percentages of PET. As we see in the test the Flakiness Index of different aggregate sample coated with plastic, for 8%,-13.492, For 6%,-16.5, For 4%,-17.4%, For 2%,-18.1%, For 0%,-19.4%, these values shows the impact of plastic coating over the aggregate, When PET was coated to the aggregate s, the values of Flakiness Index decreased as content of waste plastic increase. There is an improvement in the aggregate Flakiness Index, due to the coating of plastics over the aggregate. It could be because melted plastic improves the shape aggregate or increased area of contact the aggregate surface. This shows a lower flakiness index value indicates better particle shape, have high compatibility and low breakage/Deformation there is increase in toughness property of aggregates. Whereas a higher value indicates a higher percentage of flat and elongated particles may lead to higher tendency of pavement distress.

Based on the lab data that indicates the Flakiness Index of properties binder coated Aggregate at various binder concentrations. The Flakiness Index of different aggregate samples coated with binder is demonstrated in the test. Where test results remain constant however have superior outcome than the regular aggregate result. It could be because the liquid binder has a lower (visco-elastic) property. However, the waste plastic coated aggregate has greater elasticity.

Following evaluation of the data, it becomes clear that there is a gradual decrease in the flakiness index as the binder content climbs from 0% to 8%. This trend indicates that an increased amount of binder results in a decrease in the tendency of the aggregate particles to be flaky. Lower flakiness scores on unpaved road surfaces suggest the presence of up to 8% more spherical or cubical particles, which may increase the road's durability and stability. Reduction of flakiness can improve the interlocking of aggregate particles and increase the load-bearing capacity of the road surface. Furthermore, the effect of the concentration of the binder on the flakiness index is an important variable affecting the general effectiveness and quality of the road surface treatment. Engineers and road authority can improve the strength and lifespan of unpaved road surfaces by adjusting the amount of binder to get the desired level of flakiness. The data shows that the concentration of binder has a substantial effect on the flakiness index of the aggregate features in the treatment of unpaved road surfaces. Developing an accurate understanding of this relationship is necessary for achieving appropriate road surface performance and durability. By carefully adjusting the quantity of binder used, it is possible to accurately control the flakiness index and improve the overall quality of unpaved road surfaces.

4.4.1.2 Effect of Waste Plastic PET Content on Los Angeles Abrasion.

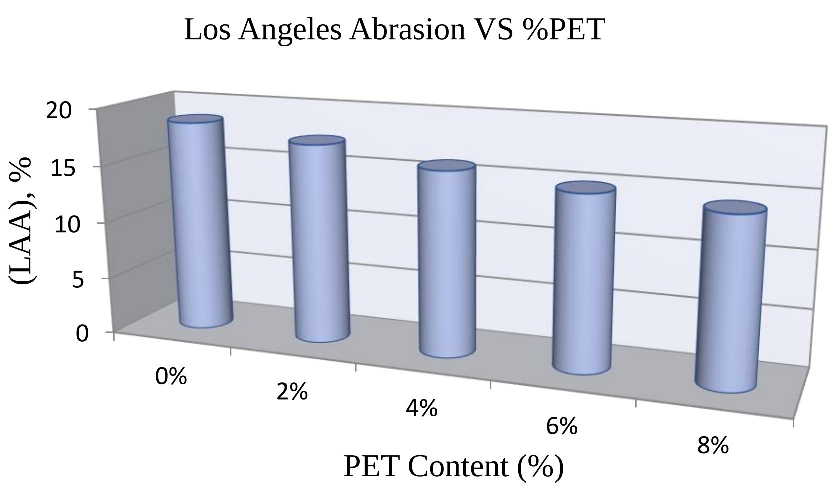

Figure 4.4: Effect of PET Content on Los Angeles Abrasion of Aggregate properties

Wear and tear over the surface of the road is caused due to repeated movement of the vehicle over the pavement. Figure 4.4 Showed that, the on Los Angeles Abrasion of properties waste plastic coated Aggregate with various percentages of PET.

According to the test for 8% plastic coating the abrasion value is 14.3% whereas for 6% is 15%, for 4% is 16% for 2% is 17.4% and for 0% (plain aggregate) is 18.6% respectively. These values show the impact of plastic coating over the aggregate, When PET was coated to the aggregate s, the values of Los Angeles Abrasion decreased as content of waste plastic increase. This show increases in the hardness property of the aggregates. The percentage of wear and tear is given by this test. This test, it showed that plastic coated aggregate had less percentage of wear and tear as compared to plain aggregate. This shows major improvement in accordance to wear and tear of aggregate. The resistance increases with the increase of coating thickness of the plastics coated. This is because coating of polymers over aggregate gives better adhesion over the surface particles. It reduces the roughness of the aggregate and thus resulting in the reduction of abrasion over the surface of aggregate.

4.4.1.3 Effect of Waste Plastic PET Content on Aggregate Crushing Value.

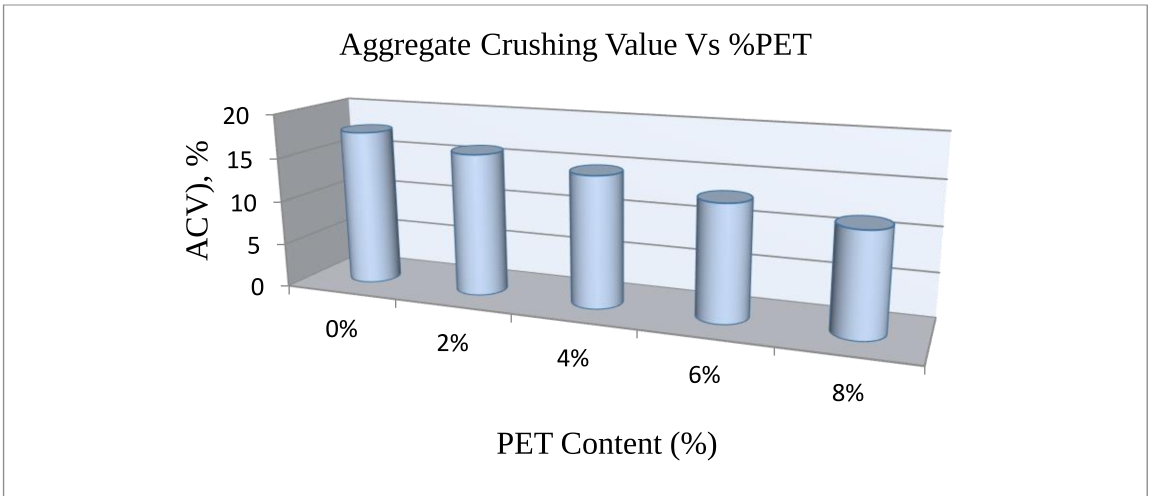

Figure 4.5: Effect of PET Content on Aggregate Crushing Value of properties.

The aggregate crushing value is a measure of how resistant a material is to crush when subjected to a progressively applied compressive load. Aggregates with a strong resistance to crushing or a low aggregate crushing value are preferable for high-quality pavement.

Figure 4.5 Showed that, the on Aggregate Crushing Value of properties waste plastic coated Aggregate with various percentages of PET. According to the test for 8% plastic coating the Aggregate Crushing Value is 11.5% whereas for 6% is 13%, for 4% is 14.8% for 2% is 16.2% and for 0% (plain aggregate) is 17.7% respectively. These values show the impact of plastic coating over the aggregate; when PET was coated to the aggregates, the values of Aggregate Crushing Value decreased as content of waste plastic increase. It means increasing the plastic content decreases the amount of mass loss when the sample undergoes crushing. Low aggregate crushing value indicates strong aggregates, as the crushed fraction is low.

4.4.1.4 Summary of the Result Waste plastic Coated Aggregate

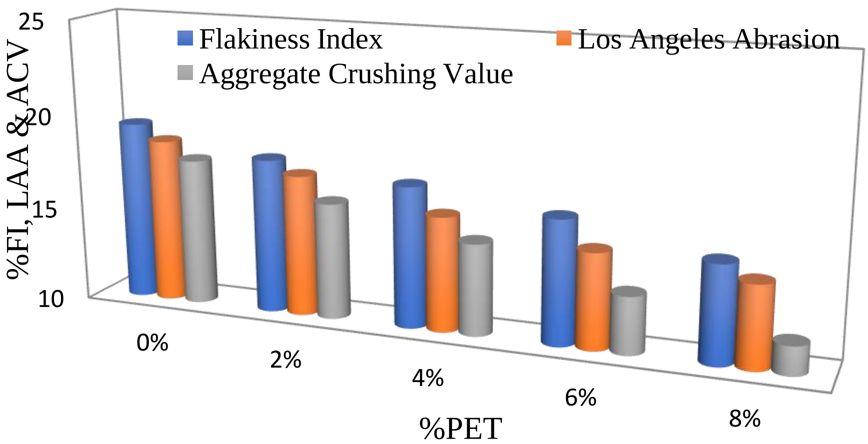

Figure 4.6 Aggregate Result Summary of Waste Plastic Coated Aggregate

The several tests conducted on both ordinary aggregates and waste plastic coated aggregates, which had various properties, were compared versus the specified standards. Figure 4.6 demonstrates that aggregates are appropriate for use in pavement construction due to their capacity to enhance strength through the application of waste plastic covering. For example, the variation in PET from 0% to 8% of coated aggregate resulted in a decrease in flakiness index of 22.16, Los Angeles abrasion of (30.06%), and crushing values of 35.02% + of normal aggregate, as shown in the above figure. This signifies that the strength of all characteristics' coated aggregate is greater than the strength of normal aggregate. A low Los Angeles abrasion test number is preferable since it implies less material detachment or distortion of the road material and suggests hardness. Aggregates with reduced flakiness indexes and crushing values would provide a longer service life for the road as well as more economical performance.

4.4.2 Performance of Binder Coated Aggregate

4.4.2.1 Effect of Binder on Flakiness Index properties of Aggregate

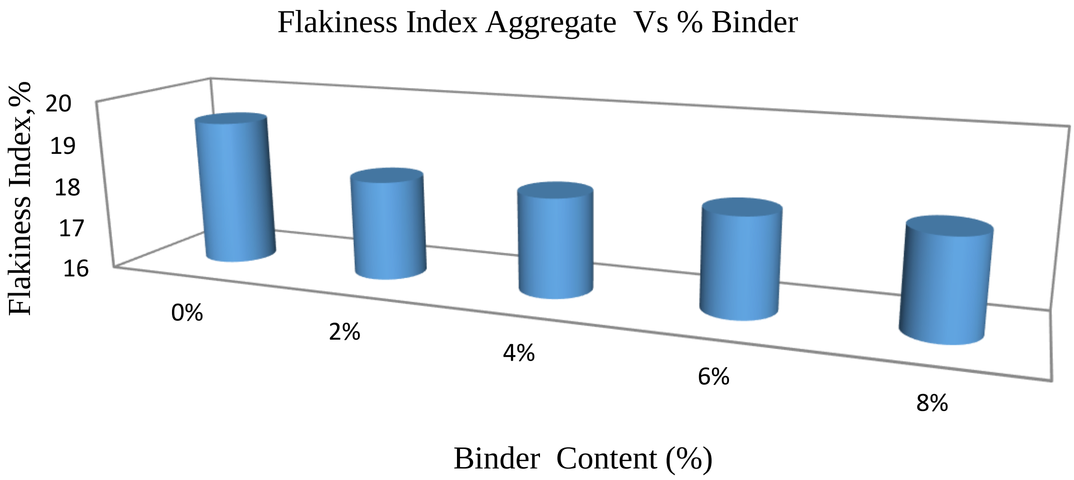

Figure 4.7: Effect of Binder Content on Flakiness Index of Aggregate properties.

Figure 4.7 depicts the Flakiness Index of properties binder coated Aggregate at various binder concentrations. The Flakiness Index of different aggregate samples coated with binder is demonstrated in the test. Where test results remain constant however have superior outcome than the regular aggregate result. It could be because the liquid binder has a lower (visco-elastic) property. However, the waste plastic coated aggregate has greater elasticity.

From the results, it becomes clear that there is a gradual decrease in the flakiness index as the binder content climbs from 0% to 8%. This trend indicates that an increased amount of binder results in a decrease in the tendency of the aggregate particles to be flaky. The binder functions as a cohesive agent that binds the aggregate particles, leading to a denser and more stable structure.

For unpaved road surfaces, a lower flakiness index indicates a higher proportion of cubical or spherical particles, potentially enhancing the road's durability and stability. Better aggregate particle interlocking can result from decreased flakiness, which raises the road surface's load-bearing capability. Furthermore, assessing the overall effectiveness and quality of the road surface treatment depends critically on how the binder content affects the flakiness index. Engineers and construction experts can enhance the durability and longevity of unpaved road surfaces by modifying the binder content according to the desired flakiness index.

The data indicates that the binder concentration significantly impacts the flakiness index of aggregate characteristics in the unpaved road surface treatment. Gaining a comprehensive understanding of this correlation is crucial to achieve the highest level of road surface performance and longevity. By precisely manipulating the amount of binder used, one may effectively regulate the flakiness index and enhance the overall excellence of unpaved road surfaces.

4.4.2.2 Effect of Binder Content on Los Angeles Abrasion, % properties of Aggregate

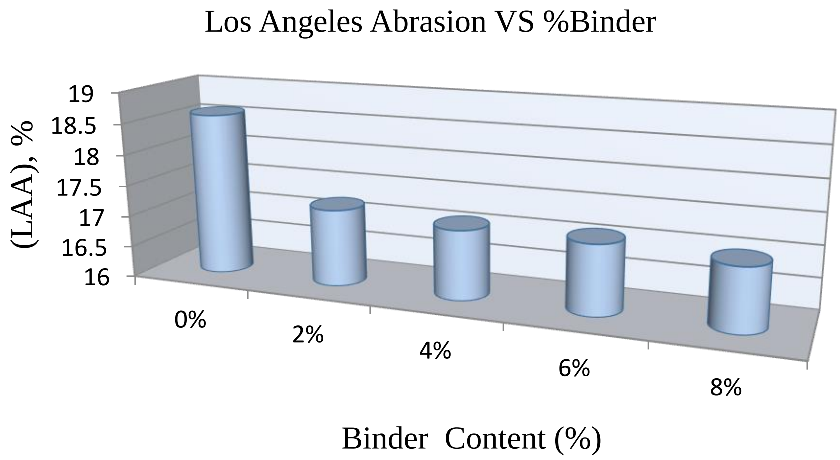

Figure 4.8: Effect of Binder on Los Angeles Abrasion of Aggregate properties

Figure 4.8 demonstrate the Los Angeles Abrasion of properties binder coated Aggregate at various binder concentrations. The Los Angeles Abrasion of different aggregate samples coated with binder is demonstrated in the test. Where test results remain constant however have superior outcome than the regular aggregate result. It could be because the liquid binder has a lower (visco-elastic) (viscous) property. However, the waste plastic coated aggregate has greater elasticity.

4.4.2.3 Effect of Binder Content on Aggregate Crushing Value, % properties of Aggregate

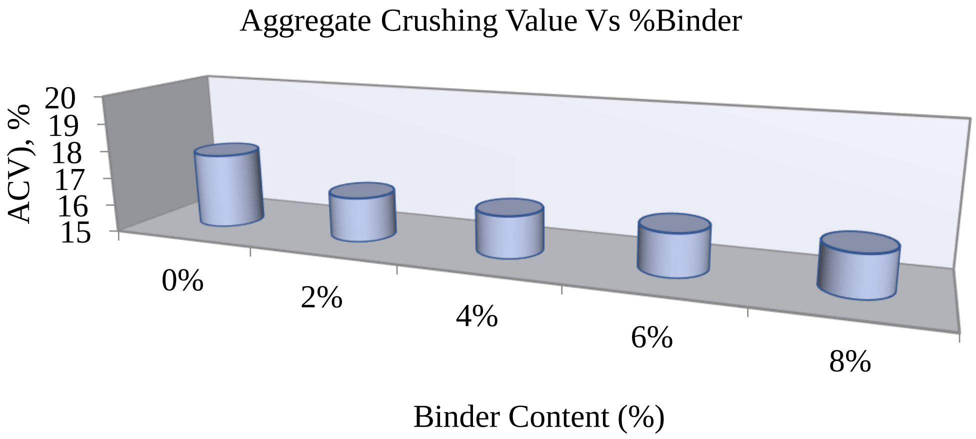

Figure 4.9: Effect of Binder Content on Aggregate Crushing Value of properties

Figure 4.9 depicts the Aggregate Crushing Value of properties binder coated Aggregate at various binder concentrations. The Aggregate Crushing Value of different aggregate samples coated with binder is demonstrated in the test. Where test results remain constant however have superior outcome than the regular aggregate result. It could be because the liquid binder has a lower (visco-elastic) (viscous) property. However, the waste plastic coated aggregate has greater elasticity.

4.4.2.4 Aggregate Result Summary for Binder Coated Aggregate

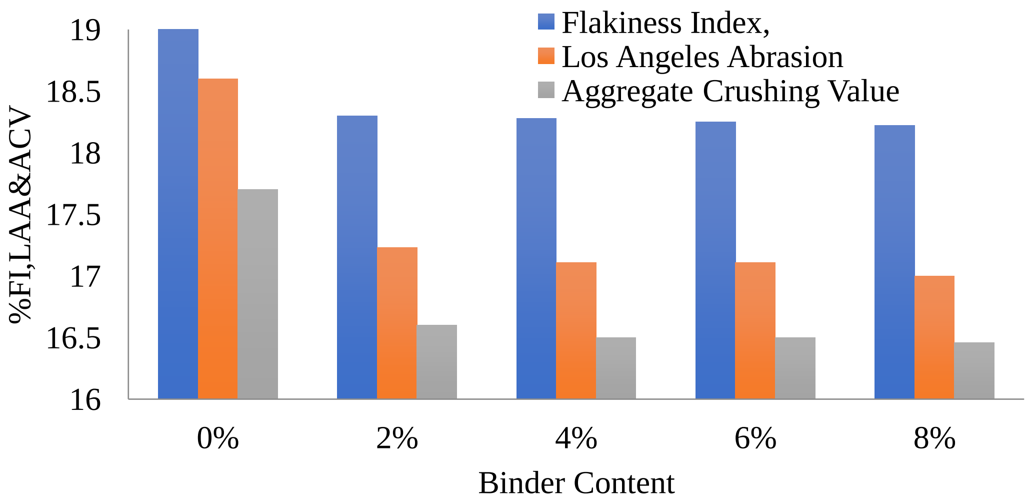

Figure 4.10: Aggregate Result Summary of vs Binder Coated Aggregate.

Figure 4.10 depicts the various properties binder coated Aggregate at various binder concentrations. The result showed that, the amount of binder has not significance influence (test results remain constant) on the aggregate properties such as Flakiness Index, Los Anglos and Aggregate crushing value. Where however have superior outcome than the regular aggregate result. It could be because the liquid binder has a lower (visco-elastic) (viscous) property. However, the waste plastic coated aggregate has greater elastic properties than binder coated aggregate.

4.5 Performance of Waste plastic Containing Binder Coated Aggregate

4.5.1 Effect of Waste plastic Containing Binder Coated Aggregate on Flakiness Index.

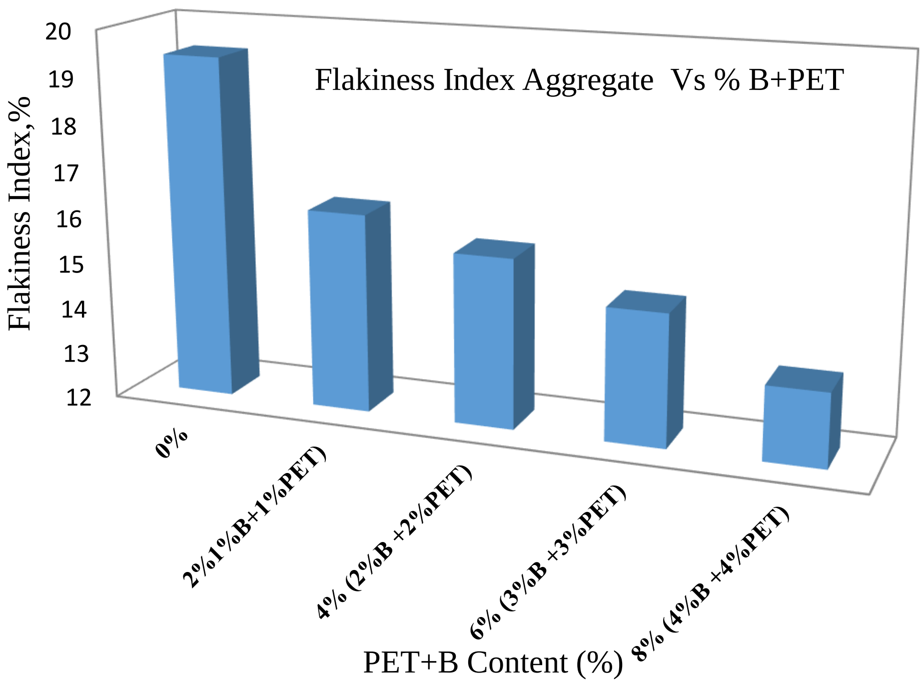

Figure 4.11: Effect of Waste plastic Containing Binder Content on Flakiness Index.

Figure 4.11 demonstrates the Flakiness Index of properties Waste plastic Containing Binder coated Aggregate with various percentages of binder and PET. As we see in the test result the Flakiness Index decreased sample coated with binder and plastic, for 8%(4%Binder +4% PET) is 13.59, For 6% (3% Binder +3% PET)-14.88, For 4% (2%Binder +2% PET -15.66%, For 2% (1%Binder +1% PET -16.20%, For 0%-19.4%, these values shows the impact of plastic Canting Binder over all the aggregate properties, When binder +PET was coated to the aggregate s, the values of Flakiness Index decreased as content of modifiers(B+PET) increase. There is an improvement in the aggregate Flakiness Index properties, due to the modifiers over the aggregate. It could be because melted plastic improves the shape aggregate or increased area of contact the aggregate surface. This shows a lower flakiness index value indicates better particle shape, have high compatibility and low breakage deformation there is increase in toughness property of aggregates. Whereas a higher value indicates a higher percentage of flat and elongated particles may lead to higher tendency of pavement distress.

4.5.2 Effect of Waste plastic Containing Binder Coated Aggregate on Los Angeles Abrasion.

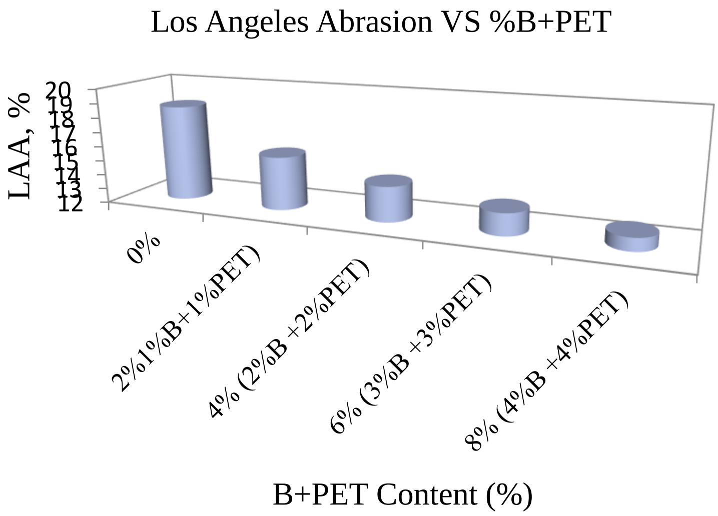

Figure 4.12: Effect of Waste plastic Containing Binder Content on Los Angeles Abrasion.

Figure 4.12 depicts the gradual drop in the abrasion value of Los Angeles. The traditional aggregate had the highest Los Angeles abrasion test rating, suggesting that it is the weakest of the samples. The Los Angeles value of the sample with plastic coating continues to fall. The sample with 8% coating has the lowest LAA value, which is only 12.87%. The maximum permissible value of Los Angeles abrasion for high-traffic roads is set at 30%. Nonetheless, none of the readings in aggregate samples exceed 30% abrasion value. The polymer coating has greatly increased the hardness of aggregates. When selecting aggregate for road construction, one of the most required properties of aggregate is its hardness [3, 10, 19]. The better the hardness, the less it would need repair or maintenance, which can save cost.

4.5.3 Effect of Waste plastic Containing Binder Coated Aggregate on Aggregate Crushing Value.

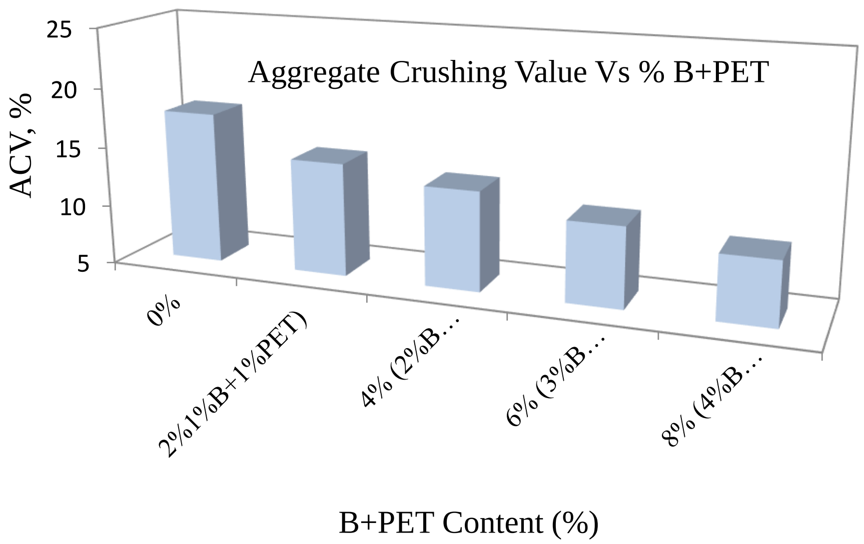

Figure 4.13: Effect of Waste plastic Binder Content on Aggregate Crushing Value.

Figure 4.13 depicts the aggregate crushing value of waste plastic Canting binder. The ACV of the conventional aggregate, which is the sample with no plastic, is 17.7%. The ACV value represents the percentage loss of aggregates from the sample in the form of fine particles. The ACV value dropped to 10.35 in a sample containing 8% plastic. As we can see in Fig. 11, there is a negative trend with higher binder with plastic%. The highest plastic% samples have the greatest possible ACV. It means that increasing the amount of waste plastic canting binder content in coated aggregate reduces the amount of mass loss when the sample is crushed. ACV is the lowest in all samples. All the other samples had values that are less than the limit.

4.5.4. Aggregate Result Summary of Waste Plastic Canting Binder Coated Aggregate

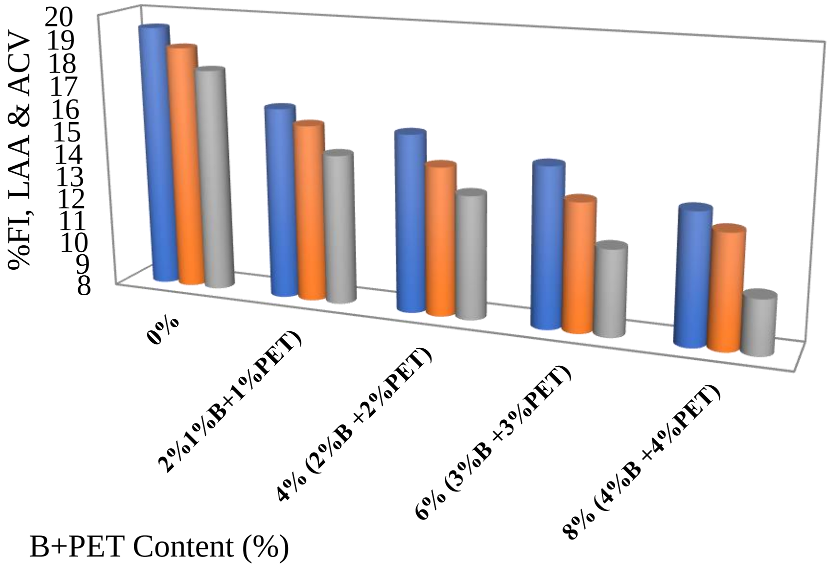

Figure 4.14: Aggregate Result Summary vs. Waste Plastic Containing Binder.

Figure 4.14 shown that, the various properties waste plastic Canting binder coated Aggregate at its various concentrations. The result showed that, the amount of PET containing binder have significance influence on the aggregate properties such as Flakiness Index, Los Anglos and Aggregate crushing value.

4.6. Result Summary and Comparison

Table 4.6: Summaries of test results.

<table>
<tr><th rowspan="2">% Modifiers</th><th colspan="5">Aggregate properties</th></tr>
<tr><th>Flakiness Index</th><th>Los Angeles Abrasion</th><th>Aggregate Crushing Value</th><th>Specification Requirements of the Project (ERA Manual)</th><th>Suitability For Road Construction</th></tr>
<tr><td colspan="4">1. For Normal Aggregate</td><td rowspan="17">1. Flakiness Index, <45%

2 Los Angeles Abrasion< 30%

3. Aggregate Crushing Value <25 %</td><td rowspan="2">Suitable</td></tr>
<tr><td>0%</td><td>19.4</td><td>18.6</td><td>17.7</td></tr>
<tr><td colspan="4">2. For Waste Plastic PET Coated Aggregate</td><td rowspan="5">Suitable</td></tr>
<tr><td>2%PET)</td><td>18.1</td><td>17.4</td><td>16.1</td></tr>
<tr><td>4% PET)</td><td>17.4</td><td>16</td><td>14.8</td></tr>
<tr><td>6% PET)</td><td>16.5</td><td>15</td><td>13</td></tr>
<tr><td>8% PET)</td><td>15.1</td><td>14.3</td><td>11.5</td></tr>
<tr><td colspan="4">3. For Binder Coated Aggregate</td><td rowspan="6">Suitable</td></tr>
<tr><td>2% Binder</td><td>18.3</td><td>17.23</td><td>16.6</td></tr>
<tr><td>4%Binder</td><td>18.28</td><td>17.11</td><td>16.5</td></tr>
<tr><td>6% Binder</td><td>18.25</td><td>17.11</td><td>16.5</td></tr>
<tr><td>8%Binder</td><td>18.22</td><td>17</td><td>16.46</td></tr>
<tr><td colspan="4">4. For Waste Plastic PET Containing Binder</td></tr>
<tr><td>2%1%B+1%PET)</td><td>16.29</td><td>15.66</td><td>14.49</td><td rowspan="4">Suitable</td></tr>
<tr><td>4% (2%B +2%PET)</td><td>15.66</td><td>14.4</td><td>13.32</td></tr>
<tr><td>6% (3%B +3%PET)</td><td>14.85</td><td>13.5</td><td>11.7</td></tr>
<tr><td>8% (4%B +4%PET)</td><td>13.59</td><td>12.87</td><td>10.35</td></tr>
</table>

The varied properties of waste plastic PET, binder, and PET incorporating binder coated Aggregate is illustrated in Table 4.6 at various concentrations. The introduction of PET and binder greatly improved the Flakiness Index, Los Angeles Abrasion, and Aggregate Crushing Value Tests. As the content of PET rises, the Flakiness Index (FI), Los Angeles Abrasion (LAA) and Aggregate Crushing Value (ACV) percentages generally fall – which shows that the mechanical properties of bitumen coated aggregate have improved. In other words, it may imply that using this kind of mixture for unpaved road construction can enhance its performance and durability.

With 2% to 8% PET and binder added, flow values increased FI, LAA, and ACV but were still superior to standard aggregates. However, in terms of types of modifiers' effects on FI, LAA and ACV; among plastic coated as well as binder coated aggregates together with combined effect modifiers (Binder with waste plastic PET). But when it comes to what modifiers do to Flakiness Index, LAAV and ACV, the flakiness index of the modified binder (PET) with waste plastics had a higher value for improving the properties of aggregates as compared with plastic coated or binder coated ones, Because the PET particles have a greater melting temperature than the binder, the sample may have visco-elastic characteristics.

The liquid increases the surface area of the aggregate and so improves its quality. Finally, all coted aggregate meets the basic requirements and is appropriate for road surface construction.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

The goal of this study was to see if waste plastic PET could be used as Aggregate and binder modifier by coating the aggregate in road construction to improve the performance of the Aggregate and to reduce the waste plastic from the land fill as well as from the environment. Relevant quality tests were carried out utilizing established testing protocols to achieve the study's goal. Laboratory examination was undertaken to investigate strength tests of aggregate, bitumen. Road performance can be improved by applying a binder and plastic covering to aggregates with varying contents (0 to 8% PET and binder) based on the result.

The following findings are formed based on the results of laboratory testing and analysis.

- At 25 °C, increasing the percentage of PET content to 8% results in a decrease in average penetration. It indicates that mixing in PET up to 8% results in an increase in bitumen stiffness and a decrease in penetrability. This has the potential to improve the durability and resilience of the bitumen, making it more suitable for road construction.
- The findings indicate that the incorporation of plastic modifiers into the binder enhances the resistance of coated aggregates to traffic-induced wear and environmental degradation. These results suggest that the use of plastic modified binder-coated aggregate can significantly enhance the durability and sustainability of unpaved road surfaces treatment.
- The findings indicate that the incorporation of waste plastic bottles containing bitumen as coated aggregate for the treatment of unpaved roads can positively influence the plastic properties of the resulting material. By adjusting the percentage of PET and binder content, engineers and road maintenance authorities can potentially tailor the plasticity of the pavement surface material to meet specific performance requirements.
- The study reveals that increasing plastic content in aggregates increases its specific gravity, providing longer life span and durability. The addition of plastic coating reduces moisture content, improving the absorbability of the sample. The moisture content absorbed by the higher plastic content is 46.6% compared to traditional aggregate, indicating that permeable pores fill up, resulting in a reduction in moisture content.

- Flakiness Index of different aggregate sample coated with plastic, for 8%-13.492, for 6%-16.5, for 4%-17.4%, for 2%-18.1%, for 0%-19.4%, these values show the impact of plastic coating over the aggregate; When PET was coated to the aggregate, the values of Flakiness Index decreased as content of waste plastic increase. This shows a lower flakiness index value indicates better particle shape, have high compatibility and low breakage/deformation there is increase in toughness property of aggregates.
- Los angles abrasion value reduced from for 8% plastic coating the abrasion value is 14.3% whereas for 6% is 15%, for 4% is 16% for 2% is 17.4% and for 0% (plain aggregate) is 18.6% respectively. These values show the impact of plastic coating over the aggregate, When PET was coated to the aggregate, the values of Los Angeles Abrasion decreased as content of waste plastic increase. This show increases in the hardness property of the aggregates. The percentage of wear and tear is given by this test. After conducting this test, it showed that plastic coated aggregate had less percentage of wear and tear as compared to plain aggregate. This shows major improvement in accordance to wear and tear of aggregate. The resistance increases with the increase of coating thickness of the plastics coated. This is because coating of polymers over aggregate gives better adhesion over the surface particles. It reduces the roughness of the aggregate and thus resulting in the reduction of abrasion over the surface of aggregate.
- Aggregate Crushing Value of properties waste plastic coated Aggregate with various percentages of PET. According to the test for 8% plastic coating the Aggregate Crushing Value is 11.5% whereas for 6% is 13%, for 4% is 14.8% for 2% is 16.2% and for 0% (plain aggregate) is 17.7% respectively. These values show the impact of plastic coating over the aggregate, When PET was coated to the aggregate s, the values of Aggregate Crushing Value decreased as content of waste plastic increase. It means increasing the plastic content decreases the amount of mass loss when the sample undergoes crushing. Low aggregate crushing value indicates strong aggregates, as the crushed fraction is low.

- Flakiness Index, Los Angeles Abrasion, and Aggregate Crushing Value, the combined effect of modifiers (Binder with waste plastic PET) had a greater improvement on the aggregate properties value than the plastic coated, and binder coated aggregate. Because the PET particles have a greater melting temperature than the binder, the sample may have visco-elastic characteristics. The liquid increases the surface area of the aggregate and so improves its quality. Finally, all coted aggregate meets the basic requirements and is appropriate for road building.

- In generally According to the data, using recycled plastic bottles with binder as a coating for unpaved road surfaces offers positive performance characteristics. The coated aggregate is a good option for unpaved road surface treatment because of its low flakiness index, adequate Los Angeles abrasion, and aggregate crushing value, which indicate that it has enough resistance to impact, abrasion, and crushing.

It was concluded that introducing waste plastic PET into the pavement material improved the aggregate b properties. This is also proof of the user utilizing PET in the asphalt industry is not minimizes solid waste in landfills as well as minimize continues emission from the asphalt through the life and material usage based on the test results, it's recommended to consider the use of waste plastic bottle coated aggregates for unpaved road construction, as they meet the requirements stated in the ERA Manual. Optimal PET Content appears that a higher PET content generally improves the mechanical properties of the aggregates. Therefore, using a PET content between 2% to 8% could lead to optimal results, balancing performance, and material costs.

5.2. Recommendation

Based on the outcomes of the study, it is strongly recommended to:

- Road authorities are encouraged to test newly discovered filler materials using this waste plastic material.
- Depending on the laboratory results and the current situation of solid waste disposal problem especially plastic bottles; this study had great findings and becomes great congratulations for developing countries like Ethiopia which have poor solid waste management systems. This study has double advantages to improve the performance of road pavements and to reduce environmental pollution through non-biodegradable PET plastics. This non-biodegradability property of plastic was a great advantage for the application of plastic in BC mixes since it resists different climatic and harsh weather condition.
- For this matter this study recommends different governmental (ERA and ACRA) and non-governmental organization involved in road construction works, it is better to include such waste material input as an important improving agent in unpaved surface treatment pavements at the certain percentage as new finding technology on unpaved road surface treatment pavement especially with high traffic volume.

5.3. Recommendation for future researchers

- Future study must be focuses different plastic type for various utilization with cost benefit analysis.
- Further Studies needed and Conducting field trials and long-term performance assessments will be essential to determine the practical implications of using such materials in real-world conditions.
- Must be focuses on utilize waste plastic for differ penetration grade with cost benefit analysis.
- Must be focuses on Estimation of CO_2 emission based on size and content.

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APPENDICES

Appendix- A: Standard Specification

S/N	Test description		Test Method	Result	Specification Requirements of the Project (ERA Manual)
1	Cleanliness and Deleterious materials, %		AASHTO T176	-	<5 passing0.075mm
2	Aggregate crushing Value		BS812-110	16	<25
3	Los Angeles Abrasion		AASHTOT96	17.4	<30
4	Durability and soundness, %	Sodium test	AASHTO T104	2.65	<12%
		Magnesium test			<18%
5	Particle shape, Flakiness, %		AASHTO T176	20.3	<45%
6	Aggregate Polishing Value		AASHTO		<50%
7	Water absorption, %		ASTMC 127	1.55	<2%
8	Specific Gravity (Bulk)	i. Coarse Aggregate	AASHTOT85	2.597	-
		ii. Fine Aggregate	AASHTOT84	2.58	-
9	Affinity for Asphalt (Coating and Stripping), %		AASHTO T-182	100	>95%
10	Absorption	i. Coarse aggregate	BS812-105.2	0.75	<1%
		ii. Fine Aggregate	BS812-105.2	1.05	Max 2%

Appendix-B: Sample collection and Preparation

Appendix-C: Ductility Test

C.1: Ductility Test Control Mix

Ductility of Bituminous Material Test					
Specification: AASHTO DESIGNATION: T 51 - 00					
Observation					
a) Bitumen grade: 80/100					
b) Pouring temperature: => 75℃					
c) Test temperature: 27℃					
d) Period of cooling in minute					
In air = 30min					
In water bath before trimming = 30min					
In water bath after trimming = 90min					
Sample No.	Test temperature	Speed (cm/min)	Ductility (cm)		Average (cm)
			(150 µm)	(75 µm)	100
1	27℃	5	100	100	
2	27℃	5	99	99	
3	27℃	5	101	101	

C-2: Ductility Test (with 2% PET +Binder)

Sample No.	Test temperature	Speed (cm/min)	Ductility (cm)		Average (cm)
			(150 µm)	(75 µm)	85
1	27℃	5	85	83	
2	27℃	5	88	87	
3	27℃	5	83	85	

C-3: Ductility Test (with 4% PET +Binder)

Sample No.	Test temperature	Speed (cm/min)	Ductility (cm)		Average (cm)
			(150 µm)	(75 µm)	90
1	27℃	5	89	99	
2	27℃	5	87	89	
3	27℃	5	91	98	

C-4: Ductility Test (with 6% PET +Binder)

Sample No.	Test temperature	Speed (cm/min)	Ductility (cm)		Average (cm)
			(150 µm)	(75 µm)	89 & 90

1	27℃	5	75	90	
2	27℃	5	71	80	
3	27℃	5	79	76	

C-5: Ductility Test (with 8% PET +Binder)

Sample No.	Test temperature	Speed (cm/min)	Ductility (cm)		Average (cm)
			(150 µm)	(75 µm)	
1	27℃	5	75	78	75&78
2	27℃	5	71	80	
3	27℃	5	79	76	

Appendix- D: Softening Point Test

D.1: Softening Point Test of Control Mix

	Softening Point of Bituminous			
	Specification: AASHTO DESIGNATION: T 53-96			
	Observation			
Sample No.	Temperature when starting heating, (°C)	Softening point Temperature in °C		Mean Temperature in °C
		(150 µm)	(75 µm)	
1	6	46	46	46
2	6	49	50	
3	6	43	42	

D-2: Softening Point Test (with 2% PET +Binder)

Sample No.	Temperature when starting heating, (°C)	Softening point Temperature in °C		Mean Temperature in °C
		(150 µm)	(75 µm)	
1	6	48	47	48 & 47
2	6	49	50	
3	6	47	44	

D-3: Softening Point Test (with 4% PET +Binder)

Sample No.	Temperature when starting heating, (°C)	Softening point Temperature in °C		Mean Temperature in °C
		(150 µm)	(75 µm)	
1	6	48	47	48 & 47
2	6	49	50	
3	6	47	44	

D.4: Softening Point Test (with 6% PET +Binder)

Sample No.	Temperature when starting heating, (°C)	Softening point Temperature in °C		Mean Temperature in °C
		(150 µm)	(75 µm)	
1	6	50	49	50&49
2	6	44	45	
3	6	56	51	
2	6	53	53	
3	6	59	55	

D.5: Softening Point Test (with 8% PET +Binder)

Sample No.	Temperature when starting heating, (°C)	Softening point Temperature in °C		Mean Temperature in °C
		(150 µm)	(75 µm)	
1	6	56	54	56 & 54
2	6	53	53	
3	6	59	55	

Appendix-E: Penetration Test

E.1: Penetration Test of Control Mix

Specification: AASHTO DESIGNATION: T 49-97						
Observation						
Sample No.	Test temperature (°C)	Time for test	Test load(gm)	Reading (0.1mm)		Average
				(150 μm)	(75 μm)	
1	25	5	100	96	94	96
2	25	5	100	94	98	
3	25	5	100	98	96	

E-2: Penetration Test (with 2% PET +Binder)

Sample No.	Test temperature (°C)	Time for test	Test load(gm)	Reading (0.1mm)		Average
				(150 μm)	(75 μm)	
1	25	5	100	95	95.5	95 & 95.5
2	25	5	100	92	91.5	
3	25	5	100	98	99.5	

E-3: Penetration Test (with 4% PET +Binder)

Sample No.	Test temperature (°C)	Time for test	Test load(gm)	Reading (0.1mm)		Average
				(150 μm)	(75 μm)	95&95.5
1	25	5	100	95	95.5	
2	25	5	100	92	91.5	
3	25	5	100	98	99.5	

E-4: Penetration Test (with 6% PET +Binder)

Sample No.	Test temperature (°C)	Time for test	Test load(gm)	Reading (0.1mm)		Average
				(150 μm)	(75 μm)	92 & 93
1	25	5	100	92	93	
2	25	5	100	90	89	
3	25	5	100	94	97	

E-5: Penetration Test (with 8% PET +Binder)

Sample No.	Test temperature (°C)	Time for test	Test load(gm)	Reading (0.1mm)		Average
				(150 μm)	(75 μm)	85&87
1	25	5	100	85	87	
2	25	5	100	81	84	
3	25	5	100	89	90	

Appendix F: Aggregate Physical Quality Test

F.1: Aggregate Crushing Value Test

Aggregate Crushing Value:			
Specification: BS 812: Part 110			
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			

F.2: Aggregate Flakiness Index Test

Aggregate Impact Value:			
Specification: BS 812: Part 110			
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			

F-3: Los Angeles Abrasion (LAA) Test

Los Angeles Abrasion Test						
Specification: ASTM C131and C535						
Sieve Size (Square Opening)		Mass of Indicated Size (gm)				Wt. of sample
		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						

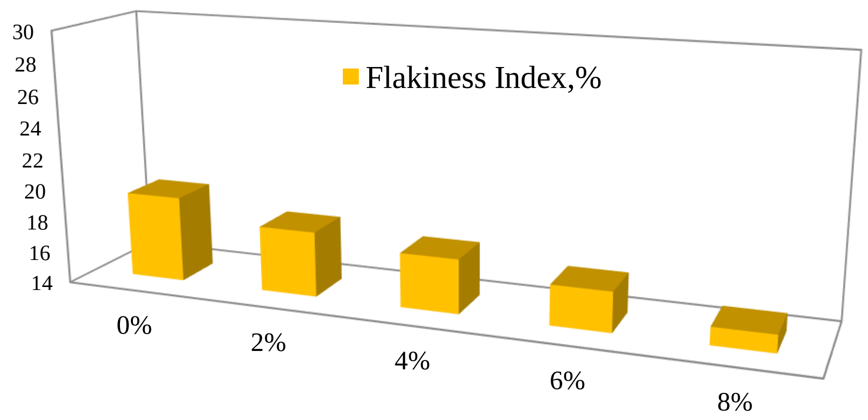
F.4: Water Absorption and Specific Gravity For (19 – 25mm) Coarse Aggregate

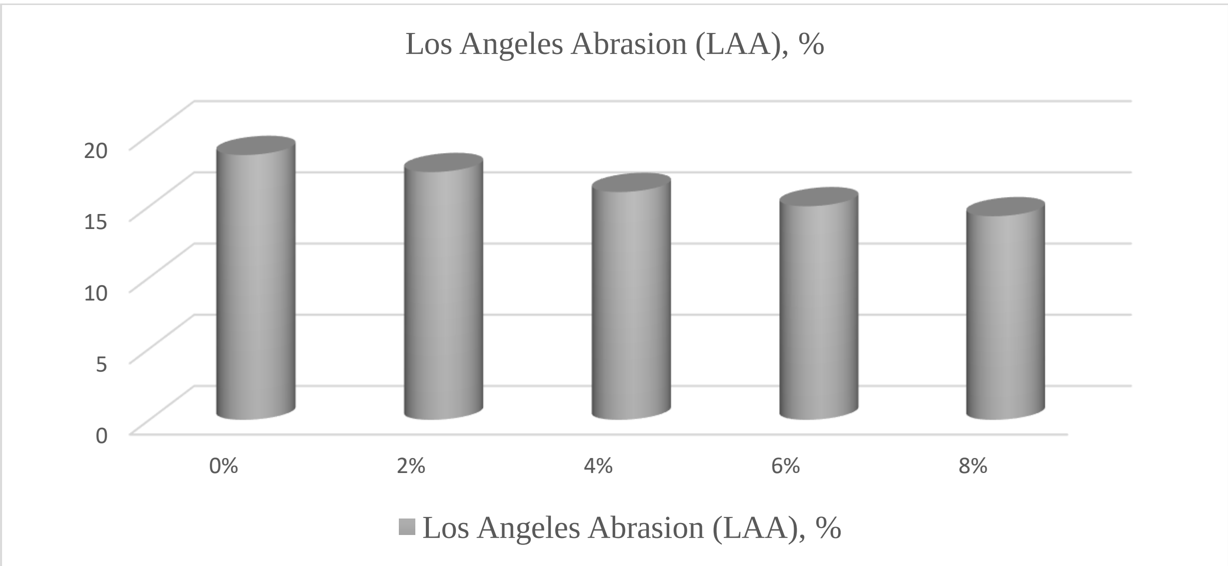
Specific Gravity and Absorption Test of Coarse Aggregate (19 - 25mm)				
Specification: AASHTO T 84				
Observation				
Observation	Unit	Trial 1	Trial 2	Average
Pycnometer No		1	2	
Temperature of water	℃	24	24	24
A. Mass of Oven Dry Sample in Air	gm	2948	2945	2946.5
B. Mass of Saturated Surface Dry (SSD)Sample in Air	gm	3005.9	2994.7	3000.3
C. Mass of Saturated Sample in Water	gm	1848	1854	1851

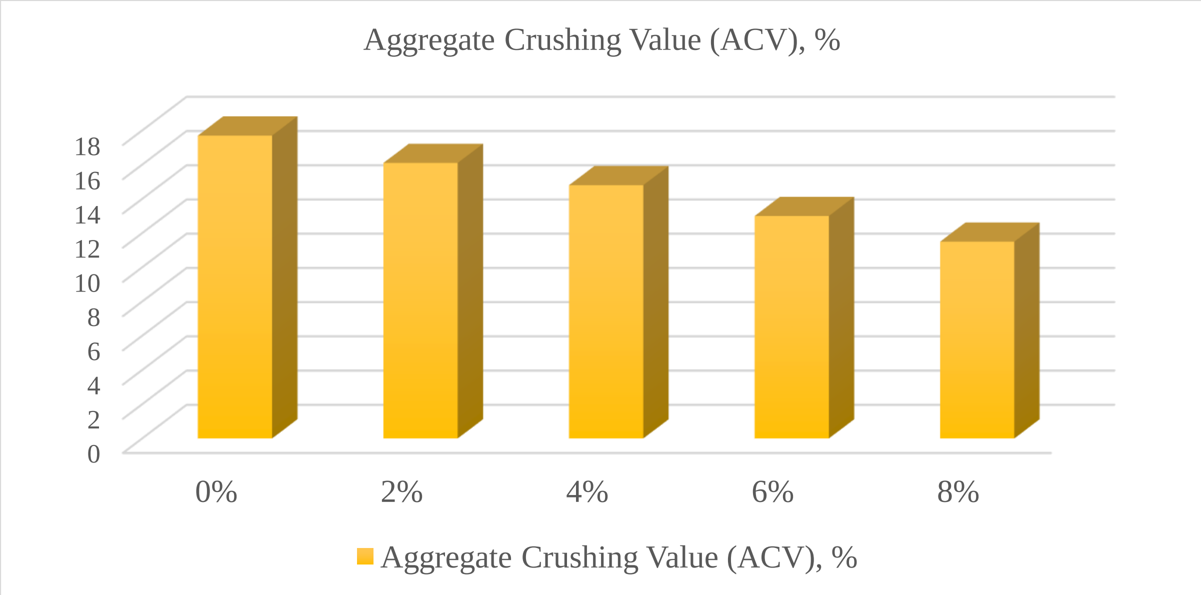
Absorption	[(B - A) *100]/A	2.0	1.7	1.8
Apparent Specific Gravity	(A/(A-C)) *K	2.68	2.70	2.69
Bulk Specific Gravity (Oven Dry)	(A/(B-C)) *K	2.54	2.58	2.56
Bulk Specific Gravity (S.S.D basis)	(B/(B-C)) *K	2.59	2.62	2.61
Correction Factor K @ 24°c = 0.9991				
Specific Gravity Reported to 0.01 Water Absorption Reported to 0.1				
Remark: 1.8 < 2 ok				

Appendix-G: Waste Plastic Coated Aggregate

% PET	Flakiness Index, %	Los Angeles Abrasion (LAA), %	Aggregate Crushing Value (ACV), %
0%	19.4	18.6	17.7
2%	18.1	17.4	16.1
4%	17.4	16	14.8
6%	16.5	15	13
8%	15.1	14.3	11.5


Flakiness Index,%
30
28
26
24
22
20
18
16
14
0%
2%
4%
6%
8%


Los Angeles Abrasion (LAA), %
20
15
10
5
0
0%
2%
4%
6%
8%
Los Angeles Abrasion (LAA), %



A+B Coated Aggregate			
% Binder +PET	Flakiness Index, %	Los Angeles Abrasion (LAA), %	Aggregate Crushing Value (ACV), %
0%	19.4	18.6	17.7
2%1%B+1%PET)	16.29	15.66	14.49
4% (2%B +2%PET)	15.66	14.4	13.32
6% (3%B +3%PET)	14.85	13.5	11.7
8% (4%B +4%PET)	13.59	12.87	10.35

Appendix-H: Comparison Result

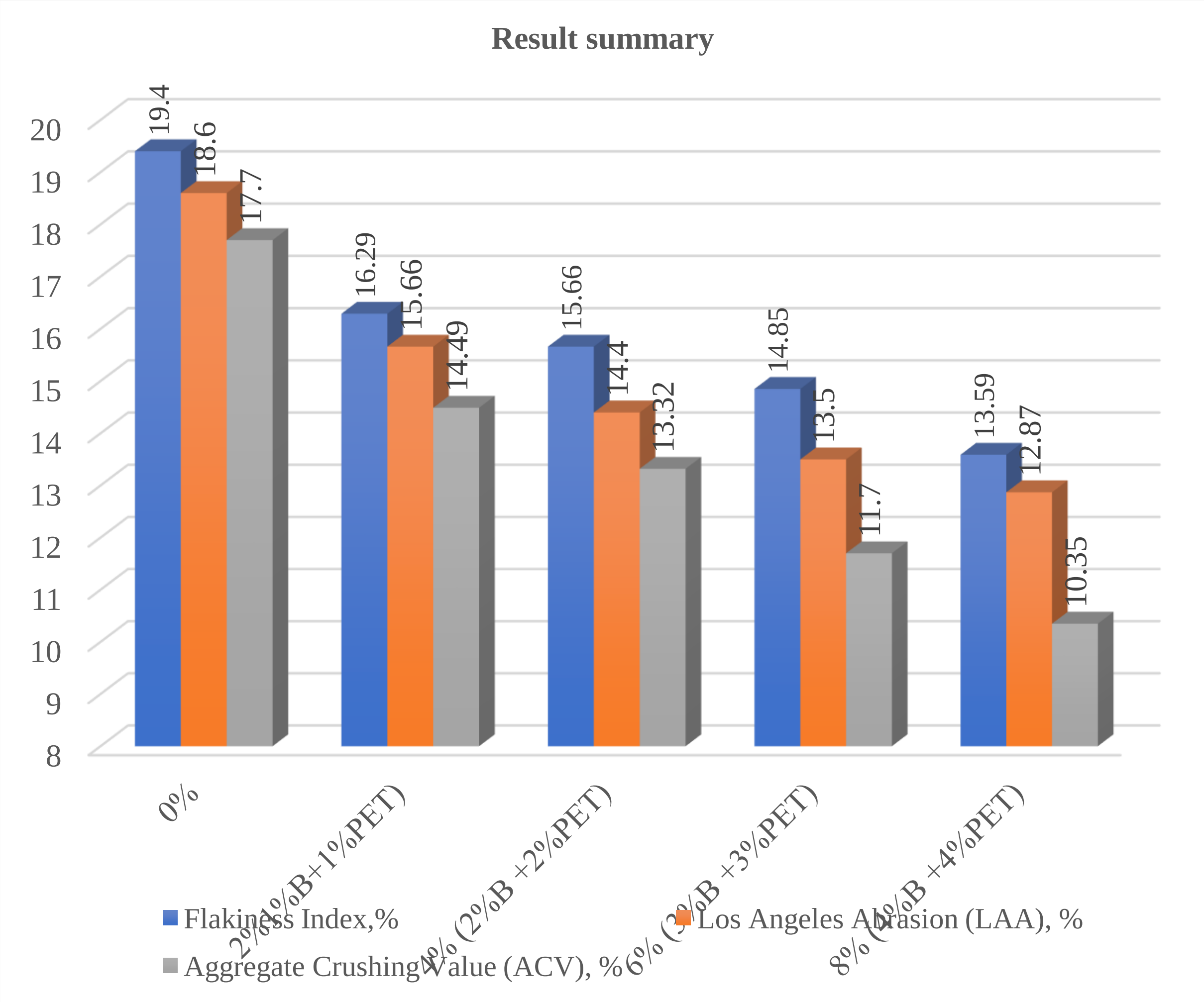
	Aggregate properties

% Modifiers	Flakiness Index	Los Angeles Abrasion	Aggregate Crushing Value	Specification Requirements of the Project (ERA Manual)	Suitability For Road Construction
1. For Normal Aggregate				1. Flakiness Index, <45% 2. Los Angeles Abrasion <30% 3. Aggregate Crushing Value <25 %	Suitable
0%	19.4	18.6	17.7		
2. For Waste Plastic PET Coated Aggregate					
2%PET)	18.1	17.4	16.1		
4% PET)	17.4	16	14.8		
6% PET)	16.5	15	13		
8% PET)	15.1	14.3	11.5		
3. For Binder Coated Aggregate					Suitable
2% Binder	18.3	17.23	16.6		
4%Binder	18.28	17.11	16.5		
6% Binder	18.25	17.11	16.5		
8%Binder	18.22	17	16.46		
4. For Waste Plastic PET Containing Binder					Suitable
2%1%B+1%PET)	16.29	15.66	14.49		
4% (2%B +2%PET)	15.66	14.4	13.32		
6% (3%B +3%PET)	14.85	13.5	11.7		
8% (4%B +4%PET)	13.59	12.87	10.35		

Appendix-I: Summery Result

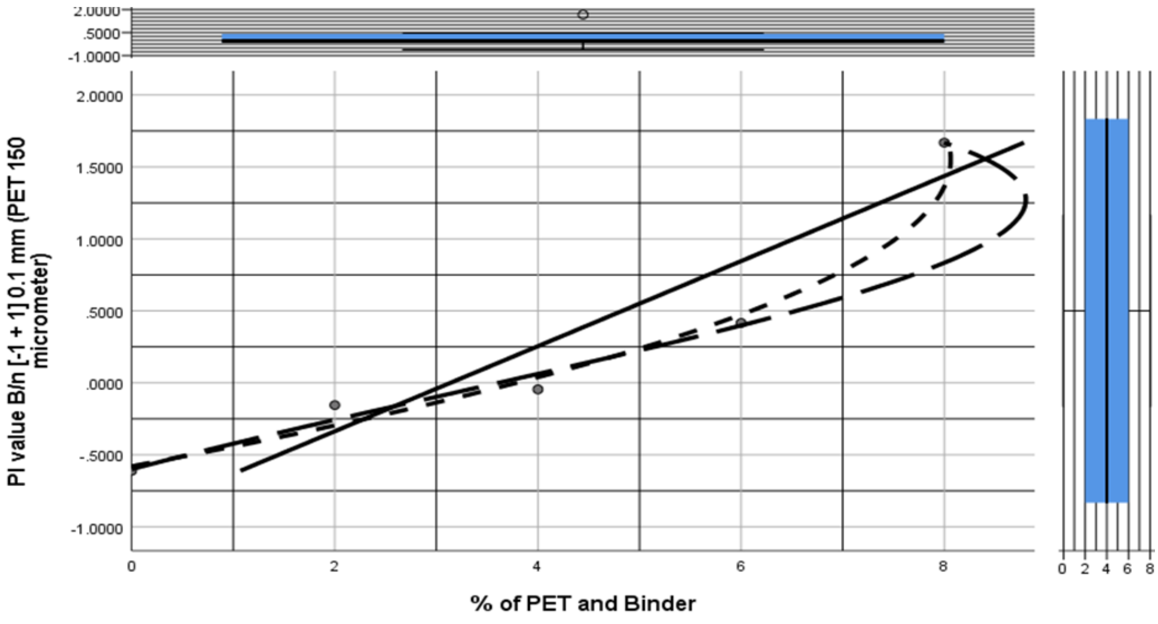
Dry process (Stability KN)	Flakiness Index, %	Los Angeles Abrasion (LAA), %	Aggregate Crushing Value (ACV), %
0%	19.4	18.6	17.7
2%1%B+1%PET)	16.29	15.66	14.49
4% (2%B +2%PET)	15.66	14.4	13.32

6% (3%B +3%PET)	14.85	13.5	11.7
8% (4%B +4%PET)	13.59	12.87	10.35

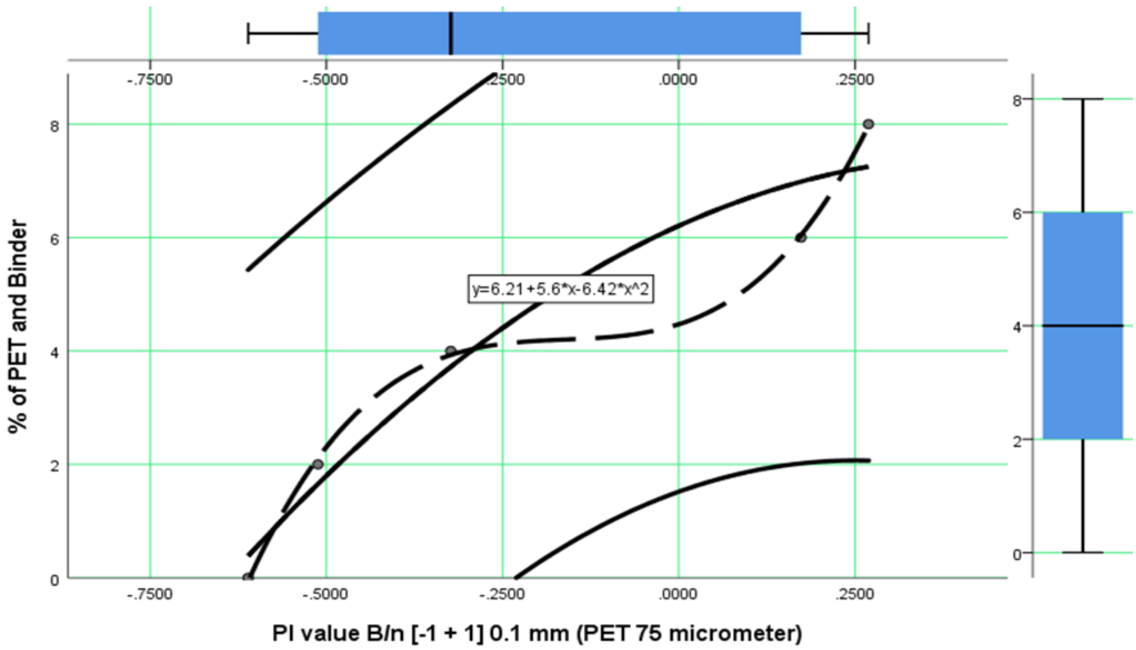


Appendix J: Statistical Analysis

J-1: Effect of PET content, binder and 150 micrometres size verses PI values.



J-2: Effect of PET content, binder and 75 micrometres size verses PI values.



J-3: Statistical results

Descriptive Statistics

	Mean	Std. Deviation	N
% of PET and Binder	4.00	3.162	5

PI value B/n [-1 + 1] 0.1 mm (PET 150 micrometer)	.254720	.8707556	5
PI value B/n [-1 + 1] 0.1 mm (PET 75 micrometer)	-.200760	.4003640	5

Correlations

		% of PET and Binder	PI value B/n [-1 + 1] 0.1 mm (PET 150 micrometer)	PI value B/n [-1 + 1] 0.1 mm (PET 75 micrometer)
% of PET and Binder	Pearson Correlation	1	.932*	.966**
	Sig. (2-tailed)		.021	.008
	N	5	5	5
PI value B/n [-1 + 1] 0.1 mm (PET 150 micrometer)	Pearson Correlation	.932*	1	.892*
	Sig. (2-tailed)	.021		.042
	N	5	5	5
PI value B/n [-1 + 1] 0.1 mm (PET 75 micrometer)	Pearson Correlation	.966**	.892*	1
	Sig. (2-tailed)	.008	.042	
	N	5	5	5

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.932[a]	.868	.824	.3653550

a. Predictors: (Constant), % of PET and Binder

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.632	1	2.632	19.721	.021[b]
	Residual	.400	3	.133		
	Total	3.033	4			

a. Dependent Variable: PI value B/n [-1 + 1] 0.1 mm (PET 150 micrometer)

b. Predictors: (Constant), % of PET and Binder

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.966[a]	.933	.911	.1196141

a. Predictors: (Constant), % of PET and Binder

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.598	1	.598	41.813	.008[b]
	Residual	.043	3	.014		
	Total	.641	4			

a. Dependent Variable: PI value B/n [-1 + 1] 0.1 mm (PET 75 micrometer)

b. Predictors: (Constant), % of PET and Binder

Appendix I: Waste Plastic PET Content specific gravity and Water Moisture Absorption properties of Aggregate

% PET	Aggregate Test	
	Specific Gravity	Water Absorption
0	2.632	1.04
2	2.631	1.02
4	2.632	0.98
6	2.633	0.91
8	2.633	0.82