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**ASSESSING THE IMPACT OF WASTE LDPE AND
SASOBIT ADDITIVES ON THE TECHNO-ECONOMIC
PERFORMANCE OF WARM MIX ASPHALT IN SRI
LANKA**

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MEng/PG Diploma in Manufacturing Systems Engineering

Department of Mechanical Engineering

University of Moratuwa

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Thesis/Dissertation submitted in partial fulfilment of the requirements for the degree
Master of Engineering in Manufacturing Systems Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

August 2025

DECLARATION

I declare that this is my own work, and this Dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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The above candidate has carried out research for the MEng in Manufacturing Systems Engineering Dissertation under our supervision. We confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Dr. L.U. Subasinghe

Signature of the Supervisor:

Date:

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ABSTRACTS

This research focuses on the use of waste LDPE (waste shopping bags) as an additive in asphalt mixtures for road construction in Sri Lanka. With the country's limited infrastructure, the accumulation of waste plastic remains a significant environmental challenge. Consequently, this research aims to address environmental concerns while enhancing road performance through the incorporation of waste LDPE in Warm Mix Asphalt (WMA) technology. The related study investigates the mechanical properties, durability, and energy efficiency of waste LDPE-modified asphalt that includes Sasobit as an additive.

Various laboratory experiments were carried out using different compositions of LDPE (2%, 4%, 6%, and 8% by weight of bitumen) along with Sasobit (3% and 5% by weight of bitumen). Results showed that 6% LDPE combined with 3% Sasobit generated the most enhanced performance for stability, flexibility, and environmental stress, like cracking and rutting, compared to the conventional asphalt mixture. Besides, the produced LDPE modified asphalt exhibited excellent workability with lower bitumen heating temperatures, which can save considerable energy consumption in producing LDPE modified asphalt.

The cost analysis confirmed that mixing both LDPE and Sasobit into the asphalt mixtures were more beneficial from an economic perspective, due to the reduction in cost of material and energy consumption. Moreover, the incorporates LDPE waste also helps cope with the plastic pollution, and it gives sustainable solution for plastic problems with other waste management and infrastructure development.

In conclusion, this research signifies that LDPE-modified asphalt mixtures can be employed as a sustainable alternative for Sri Lankan Road construction, serving the dual purpose of improving road quality and ameliorating plastic waste. Additional investigations are required to assess the long-term durability of these mixtures and to consider the incorporation of other types of plastic waste in the asphalt.

Keywords: LDPE waste, warm mix asphalt, sustainability, bitumen, road construction.

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LIST OF ABBREVIATIONS

AASHTO	- American Association of State Highway and Transportation Officials
AIV	- Aggregate Impact Value
ASTM	- American Society for Testing and Materials
CMA	- Cold Mix Asphalt
FI	- Flakiness Index
HDPE	- High Density Polyethylene
HMA	- Hot Mix Asphalt
ICTAD	- Institute of Construction Training and Development
LA AV	- Los Angeles Abrasion Value
LCA	- Life Cycle Assessment
LDPE	- Low-Density Polyethylene
OBC	- Optimum Bitumen Content
PET	- Polyethylene Terephthalate
PMA	- Polymer Modified Asphalt
PS	- Polystyrene
PVC	- Polyvinyl Chloride
RDA	- Road Development Authority
SG	- Specific Gravity
UK	- United Kingdom
USA	- United States of America
V _a	- Air Voids
VMA	- Voids in Mineral Aggregates
WMA	- Warm Mix Asphalt

CHAPTER 1. INTRODUCTION

1.1 Background of the Study

The environmental challenges associated with plastic waste have gathered increased attention globally as millions of plastic materials enter the environment each year. Single-use plastics like shopping bags, packaging, and agricultural films are some of the most significant environmental threats, as they remain in the atmosphere for hundreds of years among the different types of plastic waste. Plastic waste is also a growing problem in Sri Lanka, contributing to various environmental issues, and is difficult to manage. According to studies done recently, the per capita plastic use in Sri Lanka is about 6kg per year [1], which causes approximately 1.59 million metric tons of plastic garbage annually. The variation in per capita plastic consumption by country is illustrated in Figure 1.1.

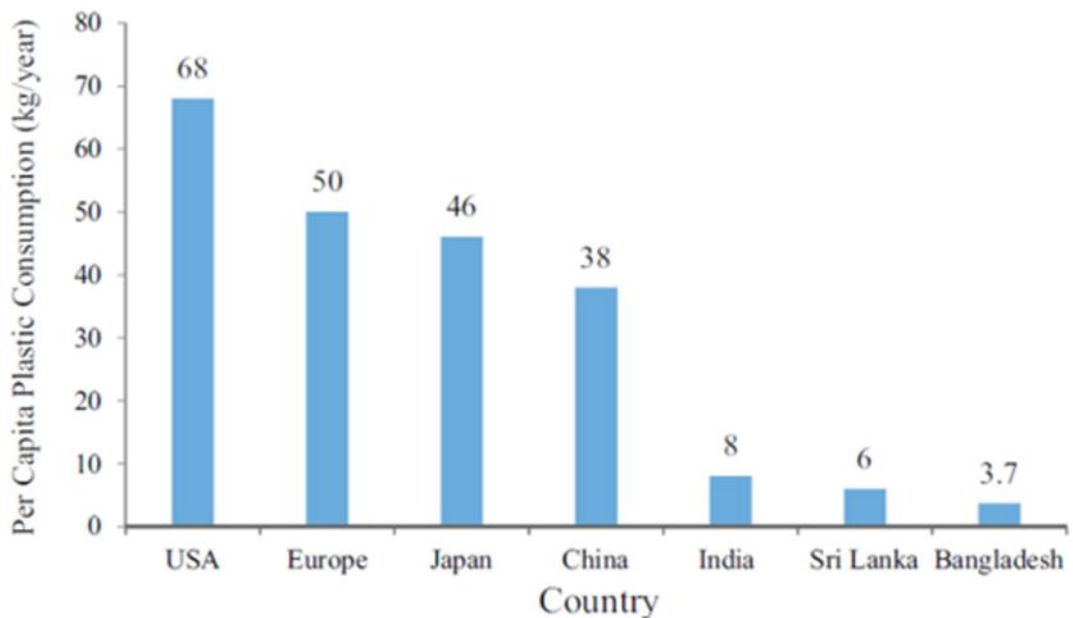


Figure 1.1 Per Capita Plastic Consumption Country-wise [2]

At the same time, the demand for plastic in different sectors is also increasing at a fast pace, resulting in a fast-growing plastic industry. Over 400 companies in Sri Lanka are engaged in plastic processing, with an annual production of about 140,000 metric tons.[2] This exponential growth, coupled with poor waste management systems, has worsened the problems associated with plastic waste and environmental pollution. Considering the current situation of rising litter and uncertainty regarding the effects of waste plastics on our ecosystem, there is an immediate need for discussion on the available technologies designed to assist in recycling and reusing waste.

To address the escalating plastic waste crisis, numerous strategies for recycling and

reuse have been undertaken both internationally and domestically. These include chemical recycling, mechanical recycling, energy recovery, and innovative material repurposing. One such promising approach is the use of waste plastics in construction materials, particularly in road construction. Incorporating plastics into bituminous mixes not only resolves some environmental issues but also improves the performance and durability of the roads. This is particularly relevant in the case of Sri Lanka, where the nation faces the dual problem of waste plastics and infrastructure deficiencies.

Sri Lanka Road Network, the most crucial component of the country, acts as the backbone of the economy and the society. Unfortunately, this road network has not been able to confront the overwhelming demand for increased traffic volume, replacement of ageing roads, harsh weather conditions, and the need for more cost-effective infrastructure options. Because of highly variable loadings and environmental intrusion, providing effective drainage of asphalt pavements and performance of asphalt pavements are vital to the quality of the asphaltic facilities. But even with all this, they can overcome their collapse, as they cannot support the weight of a society demanding more. These challenges are compounded by rising maintenance costs and increased vehicular congestion due to such lapses. Sri Lanka is facing these challenges, as mentioned above. Therefore, this study aimed to identify innovative solutions to enhance the functionality and sustainability of asphalt pavements through the recyclable waste generated in Sri Lanka.

1.2 Problem Statement

Although plastic waste, particularly single-use plastic, has received much attention in the international media, the world's eyes are turning away again, and the problem continues, especially in developing and middle-income countries like Sri Lanka. Plastic waste usually comprises an overwhelming proportion of traditional waste management methods like landfilling and incineration, which do not consider the longevity of plastic waste. As well as clogging up drainage systems, the sheer volume of waste plastics leads to environmental degradation and extra greenhouse gas emissions.

However, the rising number of these industries in Sri Lanka and poor plastic waste management solutions are leading to the same problem. Yet, sustainable solutions must be sought to reduce plastic waste while enhancing the country's 'infrastructural development'. Therefore, this research investigates the potential for plastic waste [low-density polyethylene (LDPE) shopping bags] as a green and low-cost waste management strategy to enhance asphalt pavement performance in Sri Lanka.

1.3 Research Objectives

This thesis investigates whether waste shopping bags can be used as an additive to asphalt for road construction in Sri Lanka. The objectives of the study are fourfold:

- To analyze the effect of adding waste shopping bags (LDPE) to the mixtures (WMA) using dry and wet techniques.
- To determine the optimal combination of LDPE and Sasobit as additives in the mix for improved asphalt pavement mechanical properties and performance.
- To assess the effect of waste plastic-based asphalt on durability, flexibility, and resistance to environmental stresses such as moisture damage, cracking, and rutting.
- To assess the economic advantages of utilizing LDPE and Sasobit-modified asphalt mixtures in road construction in Sri Lanka.

1.4 Research Questions

These questions serve as primary research questions guiding this thesis:

- Can the utilization of waste shopping bags (LDPE) in asphalt production contribute to reducing plastic waste and improving the quality of roads in Sri Lanka?
- What are the best mixing techniques to add waste shopping bags (LDPE) into the mix (wet or dry techniques) based on their mechanical properties (durability and resistance to environmental trends)?
- What is the amount of LDPE and Sasobit content required to enhance the asphalt mixture performance, considering the inherent properties of Sri Lankan roads?
- What are the effects of using recycled LDPE with Sasobit on the properties of asphalt mixtures, such as Marshall stability, flow, VMA, and VA, for use in Sri Lankan climatic conditions?
- What are the possible environmental and economic advantages of employing LDPE-Sasobit-modified asphalt mixtures in Sri Lankan environments?

1.5 Scope of the Study

This thesis evaluates the potential of waste plastic (shopping bags) used as an additive for asphalt production in road construction in Sri Lanka. It will mainly aim to research the mechanical properties of asphalt attics containing different percentages of waste plastic and Sasobit to observe their durability, flexibility, and resistance to environmental factors. The scope of work was kept to laboratory testing of the materials and did not encompass any field trials or full-scale implementation.

1.6 Justification for the Study

This research is important as it will overcome two significant problems Sri Lanka faces, which are the increase in plastic waste and the need for better road infrastructure. This study offers a dual benefit of addressing the issue of plastic waste and enhancing the quality of materials used in road construction by examining the utilization of waste plastic as an ingredient in asphalt production. The results could significantly affect environmental sustainability and reduce the cost of road construction and maintenance, especially for nations like Sri Lanka, battling plastic pollution and poor waste management infrastructures.

1.7 Structure of the Thesis

This thesis is structured around five chapters:

Chapter 1: Introduction — Outlines the research background, problem statement, research objectives, research questions, scope, and Justification.

Chapter 2: Literature Review – Examines the literature where waste plastic has been investigated as an additive in construction materials, especially in asphalt, focusing on the effects of additives, such as Sasobit, on the performance of asphalt.

Chapter 3: Methodology – Describes the research design, experimental setup, and materials used in the study.

Chapter 4: Analysis of Experimental Results and Discussion – Presents and analyzes the experimental results of waste LDPE-Sasobit modified asphalt mixture and discusses the findings.

Chapter 5: Conclusion, Recommendations, and Future Research – Summarizes the findings, discusses the implications, and provides recommendations for future research and practical application.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

Roads and highways currently use asphalt for construction. Pavement made of asphalt is a composite material. It consists of mineral aggregates and bitumen (used as a binder) that are mixed [3], [4] and compacted in layers. An asphalt pavement's performance is affected by several critical factors, including the properties of the elements (aggregates, bitumen, and additives) and the composition of the mixed elements. Additives, such as latex, polymers, fibres, and many chemical additives, can enhance the performance of asphalt mixtures [5].

2.2 History of Polymer Usage in Asphalt

Natural and synthetic polymers were used in asphalt in 1843. In the 1930s, Europe began using rubber latex, and in the 1950s, North America followed suit. Europe used modified asphalt before the United States, which, in the 1970s, was limited to polymer-modified asphalt due to its cost [6], [7]. The United States began using new polymers and European technologies around the mid-1980s. Australia's National Asphalt Specification includes polymer-modified binders [7].

In the 1990s and 2000s, the United States conducted the most research, followed by Canada, China, and some European countries. Marathon Ashland Petroleum LLC is the leader among companies that have filed patents on PMA during the past ten years. Fina Technology, Goodyear Tire and Rubber Company, BASF Corporation, Polyphalt LLC, and Ergon, Inc. have also reported numerous developments in marketing. The increasing popularity of polymer-modified asphalt (PMA) technology will lead to its widespread commercialization [8].

The US, France, China, and Italy lead polymer-modified asphalt (PMA) research and development, but Germany, Japan, Great Britain, Russia, and Canada have also done significant work [8].

2.3 Classification of Asphalt Mixtures

Based on the aggregate size distribution and proportion, asphalt mixtures are classified as either gap-graded or continuously graded. Gap-graded (the grading of aggregate is not continuous) mixes produce more air voids because insufficient small particles fill the spaces between the larger particles during compaction [9].

The continuously graded mixtures have different aggregate particle sizes. Consequently, it contributes to higher deformation resistance compared to gap-graded

mixtures. Fine aggregate, bitumen, and filler help to fill the voids formed by the coarse aggregates [9].

2.4 Asphalt Mixing Technologies

Asphalt mixing technologies are divided into three types based on the mixing temperature and energy consumed in the heating process. They are described below [9], [10].

2.4.1 Hot Mix Asphalt Technology

Due to its flexibility, water repellency, and weather resistance, hot mix asphalt (HMA) is the most common method for manufacturing asphalt pavement materials. HMA is produced at a mixing plant known as the Asphalt Plant. It comprises two primary elements, namely bitumen and aggregates [5], [11]. The components of aggregates are coarse and fine particles. The bitumen and aggregates are heated to a temperature between 150°C and 190°C, proportioned correctly (the aggregates comprise approximately 95% of the total mixture by weight, while the bitumen comprises approximately 5%), and mixed. The completed paving mixture is transported to the paving site by dump trucks, where it is spread by a paving machine and compacted by rollers while still hot. The pavement is ready for traffic as soon as the material has cooled to the surrounding temperature [11]. However, the HMA manufacturing process is regarded as a significant source of carbon emissions, which harms the environment [12].

2.4.2 Warm Mix Asphalt Technology

As a more sustainable alternative to HMA, warm-mix asphalt (WMA) technologies have been developed. Compared to HMA, the use of WMA lowers the mixing and compaction temperatures of asphalt mixtures by 20-40°C, which leads to lower energy consumption and greenhouse gas emissions during production without loss of mix quality [13]. Various WMA technologies have been developed, including chemical additives, organic waxes, and water-based foaming techniques, each designed to enhance the workability of the asphalt binder at lower temperatures [14]. In addition, it reduces the plant's carbon footprint, which improves working conditions at the plant and the paving site [15]. As WMA cools more slowly, it can be transported over greater distances, and the paving time can be extended [14].

WMA is used to make dense asphalt at lower temperatures. Lower asphalt temperatures reduce emissions and save energy. WMA uses 30% less energy than HMA. Reduced emissions benefit the environment. WMA is worker-friendly. Paving crews prefer WMA due to its lower temperatures and "fewer irritating fumes." Engineering benefits include better compaction, longer fatigue life, and more recycled

material. WMA has many construction uses. Construction crews can pave at lower temperatures, reducing traffic congestion. The longer paving season in colder regions allows for longer hauling distances. The longer window allows more paving in nonattainment areas.

2.4.3 Cold Mix Asphalt Technology

Cold-mix asphalt (CMA) is a more environmentally friendly alternative to HMA because it can be mixed, laid, and compacted at room temperature without heating [16]. It is a combination of graded mineral aggregate and asphalt emulsion. CMA is its low energy consumption, making it a sustainable option with minimal environmental impact. Additionally, it enhances worker safety by eliminating exposure to high temperatures and harmful fumes during mixing and paving. CMA is particularly suitable for patching work, low-volume roads, and projects in remote or colder regions where heating equipment is not practical. Its ability to be stockpiled for extended periods allows for greater flexibility in construction scheduling and lower initial production costs.

However, CMA also has limitations compared to HMA and WMA. It generally offers lower strength and durability, which makes it less appropriate for high-traffic or heavily loaded roads. Its resistance to rutting and cracking under high-stress conditions is also lower than that of HMA and WMA, which can affect long-term pavement performance.

2.5 The Primary Materials used in Asphalt Mixture

2.5.1 Aggregates

Sand, gravel, crushed rock, slag, and rock dust are complex, inert aggregates. The primary load-supporting components of HMA pavement are aggregates. As approximately 95% of the weight of dense-graded HMA consists of aggregates, the aggregates' characteristics heavily influence the performance of dense-graded HMA pavement. According to their size, HMA aggregates can be divided into coarse, fine, and mineral fillers. Coarse aggregates are typically defined as those that pass through a 2.36 mm sieve. Fine aggregates remain on the 0.075 mm sieve after passing through the 2.36 mm sieve. Mineral filler is the aggregate fraction that passes through a 0.075 mm sieve [17].

2.5.2 Bitumen

Bitumen is the viscous, heavy byproduct of crude oil refining that binds aggregates in HMA. The main components of asphalt binder are carbon and hydrogen, with trace amounts of oxygen, sulfur, and various metals. Compared to other pavement

construction materials, bitumen has several advantageous properties and characteristics (mechanical, rheological, and adhesion). Consequently, it is used as a binder in road construction projects [4]. At high temperatures, bitumen is fluid with a low viscosity, like oil. At room temperature, bitumen will resemble soft rubber. Bitumen can become highly brittle at temperatures below zero. Numerous asphalt binders contain trace amounts of polymer to improve their physical properties; these substances are referred to as polymer-modified binders. Most asphalt binder specifications were created to control temperature-induced changes in consistency [18].

2.6 Asphalt Mixtures' Properties

Mix design aims to achieve a specific set of HMA product properties. These characteristics are associated with some or all the variables comprising bitumen content, characteristics, degree of compaction, and aggregate properties, including gradation, texture, shape, and chemical composition. Table 2.1 provides a list and a brief description of several desirable asphalt mix properties [19].

Table 2.1 Properties of Asphalt Mixtures

Property	Meaning	How to maintain/enhance
Durability	Ability to withstand weathering (both air and water) and traffic abrasion	Must contain enough asphalt binders to create sufficient film thickness around aggregate particles
Fatigue Resistance	Resistance to cracking and failure under repeated traffic loading	Optimize asphalt mix design and ensure sufficient binder content
Moisture Damage Resistance	Capability to resist weakening effects due to water infiltration, preventing stripping	Apply anti-stripping agents and ensure proper drainage systems
Skid Resistance	Ability to provide sufficient friction to prevent skidding, especially in wet conditions.	Regular surface texture maintenance and use of skid-resistant aggregates

Resistant to Low-Temperature Cracking	Ability to resist cracking due to thermal contraction at low temperatures	Use modifiers like polymer binders and ensure a flexible mix design
Workability	Ease of handling, placing, and compacting during construction for proper uniformity	Maintain appropriate mix temperature and ensure a uniform aggregate gradation

Literature has shown that LDPE-modified asphalt exhibits superior durability and load-bearing capacity, particularly in high-traffic areas and regions with extreme weather conditions [20]. Additionally, plastic waste in road construction can significantly reduce reliance on virgin materials, such as bitumen, conserving natural resources and reducing the overall environmental footprint of road projects. Waste PP, PE, and rubber improve rutting resistance in asphalt mixtures [21].

Sasobit is a synthetic wax used to improve asphalt performance. It is commonly used in the production of WMA. Sasobit reduces the mixing temperature of the asphalt, improving the workability and compaction of the mixture without compromising performance [22].

2.7 Gradation Specification for Asphalt

Gradation, or particle size distribution, is one of the aggregate's most influential characteristics. Gradation in HMA facilitates accurately determining every critical property, including stability, stiffness, durability, workability, permeability, moisture damage resistance, and fatigue resistance. Typically, gradation is determined through sieve analysis. Table 2.2 and Figure 2.1 illustrate the gradation limits for the asphalt-wearing course as specified by the Institute of Construction Training and Development (ICTAD).

Table 2.2 ICTAD Gradation Limits for Wearing Course Type-1[23]

Sieve Size (mm)	Lower Limit	Upper Limit
28	100	100
20	85	100
10	66	94
5	46	74
2.36	35	58
1.18	26	48
0.600	18	38

0.300	11	28
0.150	7	20
0.075	3	12

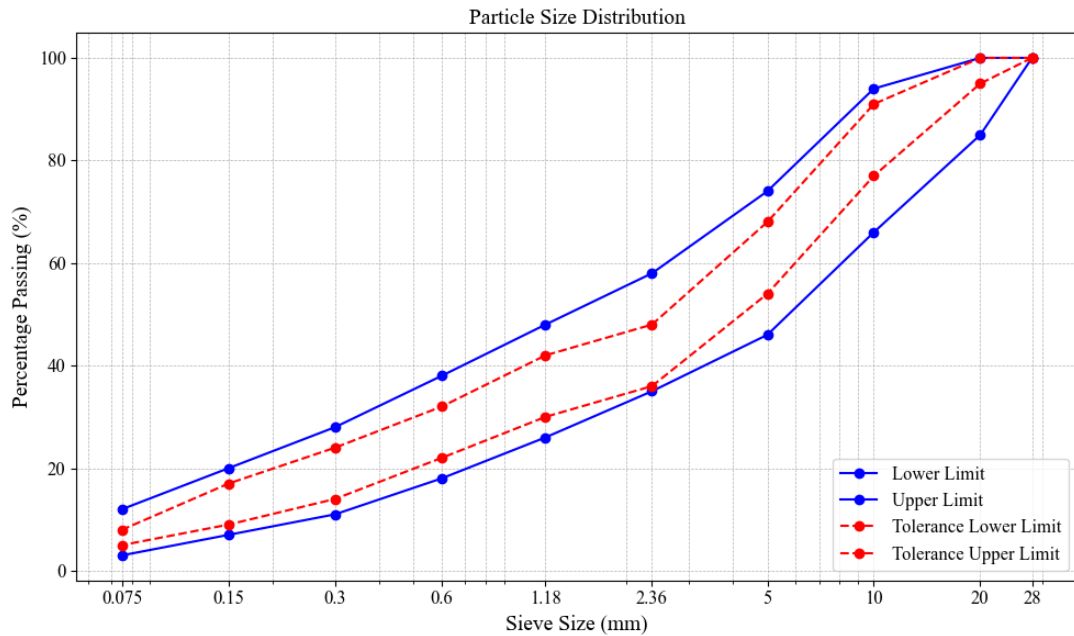


Figure 2.1 ICTAD Gradation Limits for Wearing Course Type 1[23]

2.8 Mechanical Properties Specifications for Asphalt

The ICTAD-specific requirements for the mechanical properties of the asphalt wearing course have been reviewed. Tables 2.3 present the properties of the wearing course as specified by the ICTAD.

Table 2.3 ICTAD Mechanical Properties for Wearing Course Asphalt [23]

No	Description	Low Traffic	Medium Traffic	High Traffic
1	Marshall Stability in (kN)	≥ 3.33	≥ 5.34	≥ 8.0
2	Marshall Flow (0.25mm)	8 to 20	8 to 18	8 to 16
3	Air Voids in mix percent (VIM)	3 to 5	3 to 5	3 to 5
4	Voids in mineral aggregate VMA (%) for design, VIM of 4%	≥ 13	≥ 13	≥ 13

2.9 Plastic Polymers

The Society of the Plastics Industry (SPI) introduced a unique numbering system in 1988 to enable customers and recyclers to precisely identify the type of resin used in producing a particular product. Using a coding system, manufacturers place the SPI code or number on the underside of each plastic product [24].

Plastics are made of polymers and additives. They consist of 20% to 100% Polymers. Large quantities of PP, PS, LDPE, and HDPE are used to manufacture consumer goods such as food packaging, carrier bags, and lids. PVC is also employed in manufacturing conduit pipes, flooring, bottles, and footwear [25].

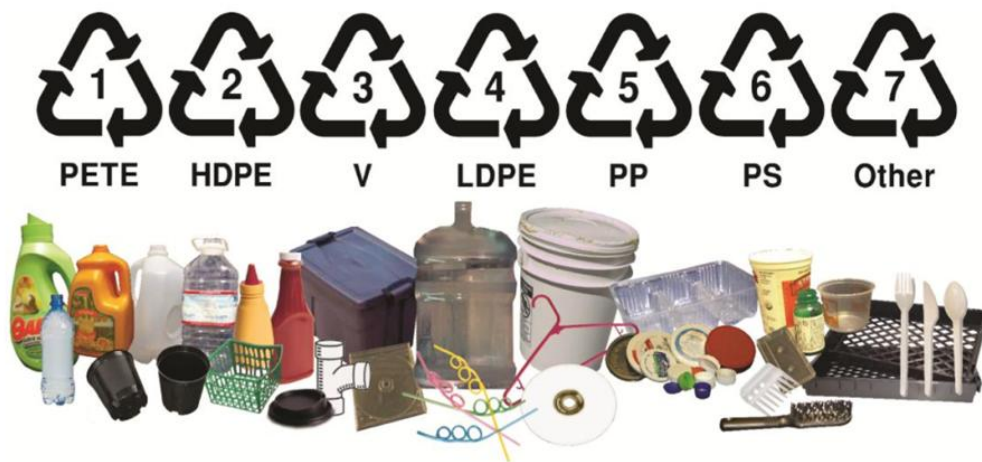


Figure 2.2 Types of Plastic Polymer

Plastic is a non-biodegradable material. Microplastic pollution is caused by non-biodegradable plastic [26]. Plastic can only be recycled 3-4 times, and during the melting process releases toxic gases [27].

Consider the environment before using plastic in road construction. Plastic waste is a global problem, so using it to improve road performance must be eco-friendly. Economics is important. This method is feasible if the benefits outweigh the costs [27]. Table 2.4 lists polymer types, their melting points, and corresponding applications.

Table 2.4 Melting Points & Applications of Polymer Types

Polymer	Melting Point (°C)	Source
Low-Density Polyethylene (LDPE)	110 – 120	Bin bags, Carrier bags
High-Density Polyethylene (HDPE)	130	Fruit Juice Bottles, Shampoo Bottles, Washing Liquid Bottles
Polyethene Terephthalate (PET)	260	Water bottles, cooking oil bottles, and Carbonated Soft Drinks Bottles
Polyvinyl Chloride (PVC)	160 - 210	Chemical Bottles,
Polystyrene (PS)	210 - 249	Food containers, also often foamed (Fast food Packaging)

2.10 Ecological Aspects of Using Modified Bitumen

According to the United Nations Environment [28] only 9% of the world's nine billion metric tonnes of plastic have been recycled. Most of it ends up in landfills, dumps, or the environment.

Plastics are separated into two recycling categories based on their molecular structure. There are thermoplastics and thermosetting plastics [25]. Thermoplastics are plastics that can be reshaped by heating. Upon initial heating, thermoset polymers develop a complex structure that is retained upon subsequent cooling but cannot be reversed upon reheating [29].

According to Gawande et al. [30] Bitumen is prepared between 155°C and 165°C. No toxic gases are produced when preparing polymer-modified bitumen with thermoplastic temperatures between 130°C and 180°C [30]. Therefore, only thermoplastics may be used to prepare plastic roads.

Only LDPE, HDPE, Polyurethane, and PET thermoplastics are used for plastic roads. Few-times-recycled black and PVC plastics release toxic gases, so they can't be used in this process.

To make plastic roads environmentally friendly, plastic must be sorted and used appropriately. This method effectively recycles thermoplastics. However, strict monitoring is crucial to making this procedure safe and avoiding releasing toxic gases into the environment.

2.11 Polymer-modified Asphalt Mixture

Various polymeric compounds were added to the asphalt mixture as additives to improve the performance of asphalt pavements. Numerous advantages arise from the polymer modification of bitumen and the asphalt mixture. These include increased thermal cracking resistance, fatigue resistance, rutting resistance, and decreased temperature susceptibility [31].

Polymers are primarily added to asphalt mixtures to modify the binder (bitumen). They can also be added to aggregates as a coating material and used as a partial replacement for a specific aggregate size. The characteristics of the modified asphalt mixture depend on various factors, including the type of polymer, how it is combined, and how effectively it works with the asphalt mixture.

There are numerous classes and types of polymers. Plastics are one of the most used polymers nowadays. Numerous studies have evaluated whether plastic waste may be incorporated into asphalt mixtures.

2.12 Integration of Plastic Waste in Road Construction

Integrating plastic waste into asphalt pavements is a novel approach to addressing waste management and enhancing road performance. Research has demonstrated that plastic waste, including LDPE, can modify the properties of asphalt binders, resulting in improved performance characteristics such as increased stiffness, enhanced resistance to rutting, and reduced susceptibility to thermal cracking [30].

Incorporating LDPE into asphalt mixtures involves blending shredded plastic particles with the binder, either directly (wet process) or through a dry process where the plastic is mixed with aggregates before adding the binder, and a third procedure uses waste plastic as a partial replacement for aggregate sizes.

Figure 2.3 illustrates the dry process used in road construction [32]. Before adding bitumen, the dry process combines plastic polymer with hot aggregates to form an aggregate surface layer. This coating layer would improve aggregate adhesion and engineering properties, improving the asphalt mixture's durability based on plasticity and mixing conditions. Only plastic polymers can be processed dry [30], [33].

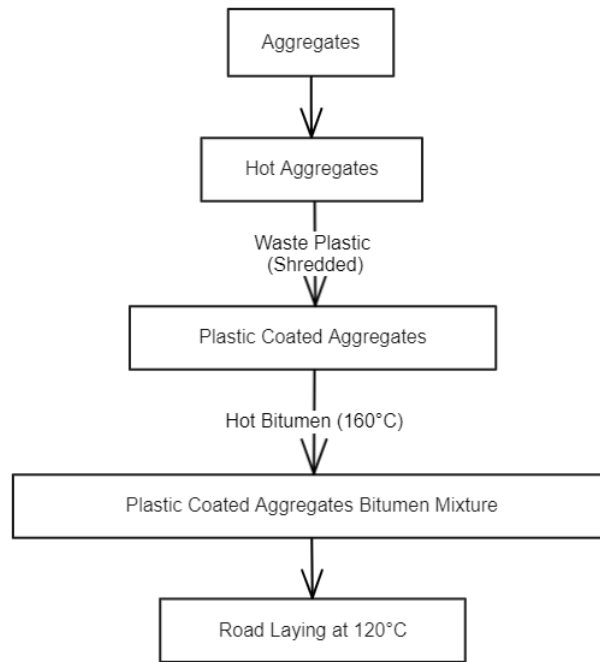


Figure 2.3 Dry Process of Adding LDPE

Figure 2.4 illustrates the wet process used for road construction. Before coating the waste plastic with aggregate, the waste plastic is heated and mixed with the bitumen mixture [32]. Therefore, the fundamental difference between the dry and wet processes is how waste plastic is incorporated into the mix before its application to roads. Consequently, heat is required for both processes that add waste plastic.

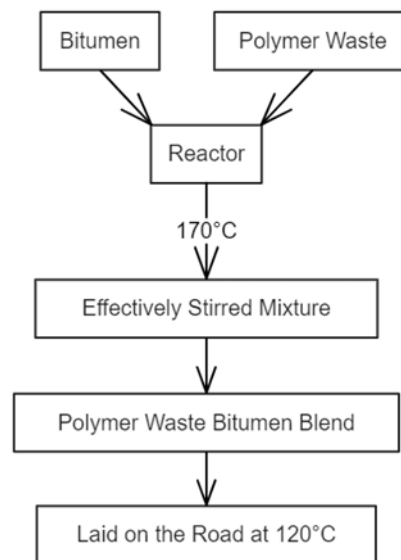


Figure 2.4 Wet Process of Adding LDPE

The properties of modified bitumen depend on numerous variables, including polymer-bitumen characteristics, mixing conditions, and compatibility. There are two

ways to incorporate polymers into bitumen. The first is to add latex polymers, which allow for relatively simple polymer dispersion. The second step is mixing solid polymers with bitumen, which requires a high-shear mixer to produce a uniform mixture [8]. The dry process only applies to plastic waste, whereas the wet process applies to rubber, etc. [30].

Alternatively, portions of mineral aggregates can be replaced with polymers of the same size as mineral aggregates. This approach is predominantly used to incorporate waste plastic into the asphalt mixture.

Studies have shown that LDPE-modified asphalt exhibits superior durability and load-bearing capacity, particularly in high-traffic areas and regions with extreme weather conditions [20]. Additionally, plastic waste in road construction can significantly reduce reliance on virgin materials, such as bitumen, conserving natural resources and reducing the overall environmental footprint of road projects [21].

2.13 Economic Aspects of Using Modified Bitumen

Bitumen is used to build roads. Plastic roads reduce bitumen usage by 10%, and on a one-km-long, four-meter-wide road, waste plastic can save 1 ton of bitumen [34]. The economic viability of using LDPE-modified WMA in Sri Lanka depends on factors such as the cost of plastic waste collection and processing, the availability of Sasobit and other WMA additives, and the potential savings in road maintenance and repair. While initial investments in technology and infrastructure may be significant, the long-term benefits of reduced maintenance costs, improved road performance, and environmental conservation could provide substantial returns. [35] Moreover, using locally sourced waste materials aligns with the principles of the circular economy and sustainable development, contributing to national efforts to reduce plastic pollution and enhance resource efficiency. The lifespan of the roads has nearly doubled, which reduces future maintenance costs and saves the government money.

2.14 Engineering Practices for the Use of Plastic Waste in Asphalt

Some researchers have assessed the field performance of waste plastic-modified asphalt pavements and their laboratory performance. Table 2.5 shows Engineering practices by country for the use of waste plastic in asphalt.

Table 2.5 Engineering Practices by Country for the Use of Waste Plastics in Asphalt

Country	Description	Details	Reference(s)
India	Roads built with used plastics employ the dry method to modify asphalt pavements. Over 2000 km of roads replaced	No potholes, cracks, or ruts were observed. The Indian Highway Congress and the National Rural Highways Development Agency released the guidelines on waste plastic in bituminous mixtures.	[36]
USA	San Diego constructed the first asphalt road using a bitumen binder from recycled plastic instead of petroleum-derived bitumen.	No further field performance results were provided.	[36], [37]
UK	Durham County Council used MacReburs recycled plastic to repave a section of the A689 and Carlisle Airport's runways.	The Department of Transportation contributed \$1.6 million to extend Cumbria's recycled plastic and asphalt road. Guidelines for plastic asphalt use are being developed.	[36], [38]
Africa	The Kouga municipality in South Africa is constructing the first plastic road.	One kilometer of the plastic road would require around 700,000 plastic bottles or 1.8 million plastic bags.	[36], [39], [40]

Mexico	Plastic waste is tested on cycle lanes, rural roads, and airport runways.	Follow-up reports are available, but the long-term effects of many pilot projects are still unknown.	[36], [41]
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2.15 Polymer-modified Asphalt Construction for Sri Lanka

The Asset group of companies in Sri Lanka has utilized waste plastic in road building by incorporating plastic into asphalt mixtures. This method decreased the amount of waste sent to landfills [42].

According to Economynext [43], Sri Lanka's first plastic road is a 500m section between Ratmalana and Borupana. Economynext [43] stated that waste plastic on this road is coated with aggregate before being coated with bitumen. In addition, the dry process is being implemented in the pilot project in Sri Lanka. However, many Sri Lankan professionals have yet to accept this technology.

2.16 Past Research Findings on Waste LDPE as an Asphalt Additive

Previous research consistently highlights the advantages of incorporating LDPE into asphalt mixtures. Numerous studies have reported that LDPE-modified asphalt exhibits superior mechanical properties, including stiffness, enhanced rutting resistance, and higher Marshall stability values compared to conventional mixes. At polymer contents of 3%, 5%, and 7%, LDPE has been shown to reduce rut depth by 13%, 24%, and 33%, respectively [44]. Beyond performance improvements, LDPE provides significant economic and environmental benefits, enabling the reuse of up to 750 kg of plastic waste per kilometer of pavement while achieving stiffness enhancements of 171% and 125% at 25°C and 35°C, respectively [45].

Experimental investigations further reinforce these findings. At inclusion levels of 6–7.5% LDPE demonstrates particularly strong performance. For instance, at 6% modification, asphalt mixtures achieved a 150.9% increase in stability, improved deformation resistance, and greater resistance to moisture-induced damage compared to conventional mixtures [46]. Similarly, at 7.5% LDPE content, Marshall stability values nearly doubled from 977.18 kg to 2103.44 kg, while bitumen consumption decreased by 7.05% [47]. Collectively, these results confirm that LDPE not only enhances the mechanical and durability performance of asphalt but also extends pavement service life and supports sustainable waste management practices [44], [45].

2.17 Past Research Findings on Sasobit as an Asphalt Additive

Research has demonstrated that incorporating Sasobit, an organic additive, is a promising modifier in both WMA and HMA. Studies have shown that Sasobit lowers mixing and compaction temperatures by approximately 7 °C compared to conventional mixtures, reduces fume emissions, and enhances rut resistance [48], [49]. Moreover, performance evaluations such as Marshall stability, resilient modulus, and fatigue testing have demonstrated that Sasobit-modified mixtures generally perform better than conventional HMA, with higher stability and flexibility values at optimal dosages (around 3%) [49], [50].

Several experimental investigations have confirmed that Sasobit improves the mechanical and volumetric properties of asphalt mixtures. For instance, Marshall stability, flow, specific gravity, and voids parameters all improved when Sasobit was introduced in proportions of 1–3% by bitumen weight [51]. Likewise, Sasobit enhances bitumen properties such as penetration, softening point, and stiffness, while also reducing abrasion loss [50]. However, concerns remain regarding long-term durability, particularly moisture susceptibility. Research indicates that Sasobit-modified WMA exhibits improved resistance to moisture damage when combined with anti-stripping agents such as hydrated lime, which increases crack resistance [52]. Overall, existing findings consistently highlight Sasobit as an effective WMA additive, improving performance, reducing environmental impact, and contributing to the development of greener pavements.

CHAPTER 3. METHODOLOGY

3.1 Research Design Method

This study aims to provide an environmentally sustainable road construction process in Sri Lanka by improving the applicability of waste LDPE shopping bags. The experimental design utilized in the research is deployed to evaluate if and how effectively waste LDPE can be incorporated into asphalt mixtures. The analysis is conducted in various phases. Figure 3.1 illustrates the process flow diagram of research methodology.

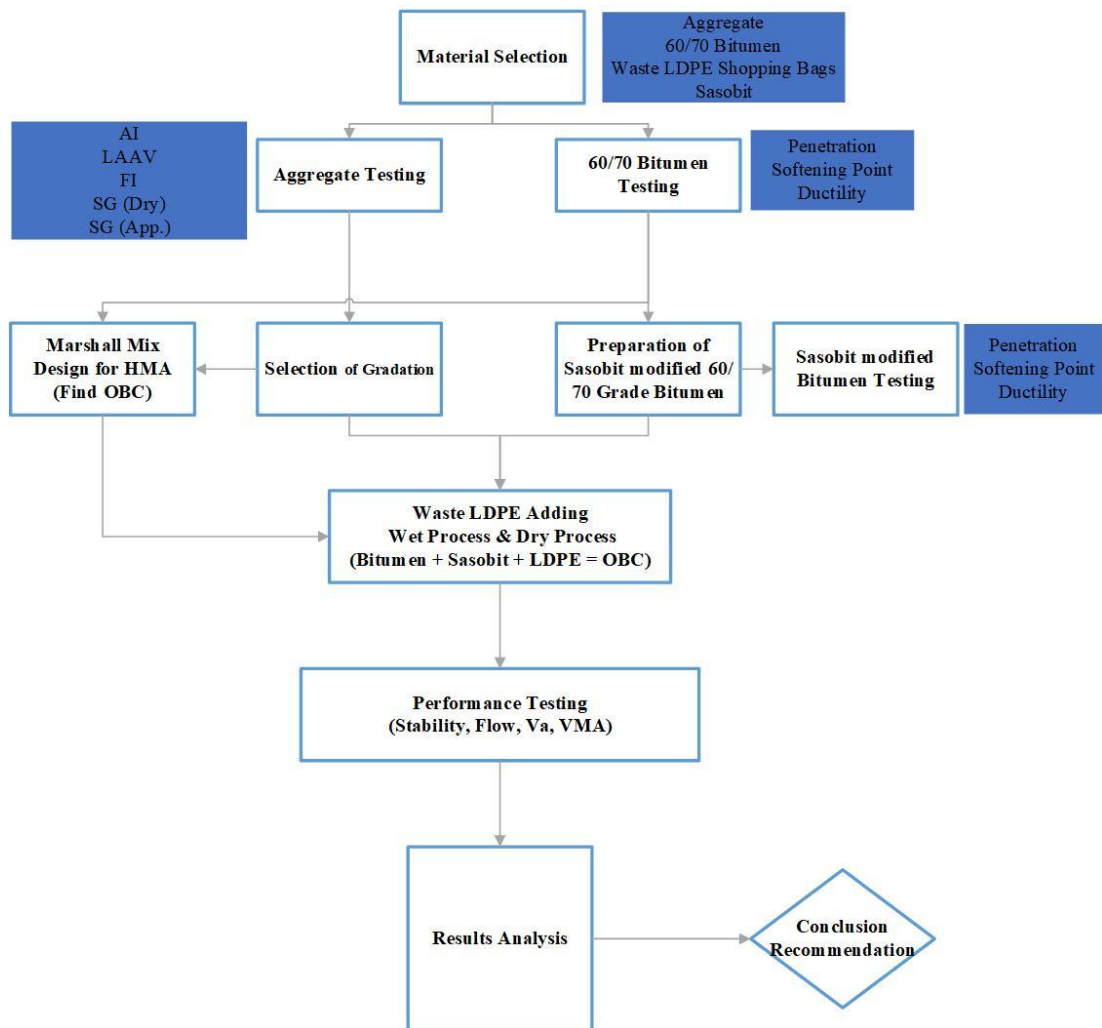


Figure 3.1 Process Flow Diagram of Research Methodology

3.2 Method of Data Collection

3.2.1 Primary Data Sources

Primary data are collected from two main sources.

- RDA, Asphalt Plant at Keragala: This facility offers valuable insights into the asphalt production process.
- Laboratory Investigations (RDA, Research & Development Division, Central Laboratory, Ratmalana): Comprehensive laboratory analyses evaluated the physical and chemical characteristics of the materials and the efficacy of the formulated asphalt mixtures.

3.2.2 Secondary Data Sources

Secondary data is obtained from an extensive literature review encompassing

- Literature Review Articles: Prior research on the application of waste materials in asphalt and road construction.
- Books and Journals: Scholarly texts and peer-reviewed journals offering comprehensive analyses and case studies pertinent to the research.
- Standard Specifications: Documents from the American Society for Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (AASHTO), and ICTAD establish guidelines and benchmarks for material testing and mix design.
- The integration of primary and secondary data facilitates a comprehensive understanding of the subject and underpins the formulation of a rigorous methodology.

3.3 Sample Size and Sampling Techniques

3.3.1 Material Collection

Table 3.1 Type of materials and their sources

Material	Source
Aggregates - Dust (0-5mm), Chips (5-12.5mm), Three-quarter (12.5-20mm)	RDA Asphalt Plant at Keragala
60/70 Grade Bitumen	RDA Asphalt Plant at Keragala
Sasobit	Imported from KML International (Pvt) Ltd, India

Figure 3.2 illustrates the various materials used in asphalt production, and Table 3.1 summarizes these materials and their respective sources.



Figure 3.2 Type of Materials

3.3.2 Sampling Techniques

The samples are selected to represent the typical conditions and materials utilized in constructing roads in Sri Lanka. Extensive testing confirms the suitability of these materials for use in asphalt mixtures.

3.4 Testing of Materials Properties

3.4.1 Aggregates

The test comprises an assessment of Aggregate Impact Value (AIV), Los Angeles Abrasion Value (LAAB), Flakiness Index (FI), Dry Specific Gravity (SG-Dry), Apparent Specific Gravity (SG-App), and Water Absorption, all conducted with ASTM and British Standards.

Road construction requires the use of aggregate materials that meet specific specifications, including testing for gradation on materials with varying sizes. Figure 3.3 presents various sizes of aggregate materials. The sieve analysis was conducted to

classify the aggregates used in asphalt mixtures into four categories based on their particle sizes, which are HB#01 (0-5 mm), HB#02 (5-10 mm), and HB#03 (10-14 mm), HB#04 (14-22 mm) to ascertain their particle size distribution is essential for achieving a well-graded mix that can distribute load and interlock effectively.



Figure 3.3 Sizes of Aggregate Materials

3.4.2 Bitumen

Bitumen 60/70 is tested for physical properties, including penetration, softening point, and ductility. Penetration tests measure the hardness or softness of the bitumen, softening point tests determine the temperature at which the bitumen becomes sufficiently soft, and ductility tests measure the bitumen's ability to deform under stress. Figure 3.4 illustrates a sample of bitumen.



Figure 3.4 Bitumen Sample

3.4.3 Sasobit

Table 3.2 provides the Properties of the Sasobit. These tests ensure that Sasobit can be effectively integrated into the asphalt mix, lowering mixing and compaction temperatures and enhancing asphalt's resistance to deformation.

Table 3.2 Sasobit Data Sheet

Test	Test Method	Unit	Result	Specific Limit	
				Min	Max
Congealing Point	ASTM D 938	°C	101	100	110
Penetration at 25°C	ASTM D 1321	0.1 mm	<1	0	2
Penetration at 65°C	ASTM D 1321	0.1 mm	11	0	13
Brookfield viscosity at 135°C	Sasol 1010	cP	12	10	15

3.4.4 Waste LDPE Shopping Bags

Waste LDPE shopping bags are cleaned and shredded for use in the asphalt mix. Cleaning removes contaminants, and shredding reduces the LDPE to small, manageable pieces. Previous research has been reviewed to understand LDPE's behaviour when mixed with bitumen, including its potential impact on the mix's performance.

3.5 Preparation of Conventional Mix and Marshall Tests

3.5.1 Blending Proportion

The conventional asphalt mix is prepared without waste LDPE or Sasobit. The blending percentages of aggregates and bitumen are adjusted to maintain standard guidelines, creating consistency and accuracy in test results.

The weight of the aggregates for each size was measured based on the blend ratio, with the total aggregate percentage varying from 96% to 94% in decrements of 0.5%. The required weight of the aggregate was heated to 180°C. Table 3.3 provides a blending proportion of the aggregate materials and bitumen for each specific case.

Table 3.3 Blending Proportions for each Specific

Specimen No	Weight of total sample (g)	% of bitumen content by total mix	Weight of bitumen (g)	Weight of aggregate (g)
A-1,2,3	1200.00	4.0	48.00	1152.00
B-1,2,3	1200.00	4.5	54.00	1146.00
C-1,2,3	1200.00	5.0	60.00	1140.00
D-1,2,3	1200.00	5.5	66.00	1134.00
E-1,2,3	1200.00	6.0	72.00	1128.00

In this study, the Marshall Mix design method was used to prepare and evaluate asphalt specimens, following the standards outlined in ASTM D6926 and ASTM D6927. The specimens were cylindrical, with a diameter of 101.6 mm (4 inches) and a height of 63.5 mm (2.5 inches). Figure 3.5 illustrates the Marshall Compaction Mould.



Figure 3.5 Marshall Compaction Mould

The compaction mould assembly was preheated to 160°C. Bitumen of 60/70 penetration grade was also heated to 150°C and added to the aggregate in the appropriate percentages. Both the heated aggregate mixture and bitumen were then mixed.

The heated aggregate and bitumen were then placed into a casting mould preheated in an oven at 160°C. The mould was then moved to a Marshall compaction machine, with the temperature maintained between 140-150°C, and 75 blows were applied to each side of the sample, which is appropriate for simulating heavy traffic conditions. Figures 3.6 & 3.7 illustrate the Marshall compaction machine and the Marshall stability and flow testing machine, respectively.



Figure 3.6 Marshall Compaction Machine



Figure 3.7 Marshall Stability & Flow Testing Machine

Each sample was labeled and kept separate for different percentages of bitumen (4%, 4.5%, 5%, 5.5%, and 6%), with three samples prepared for each percentage. Figure 3.8 illustrates the Marshall mix design samples prepared with 4.5% bitumen.

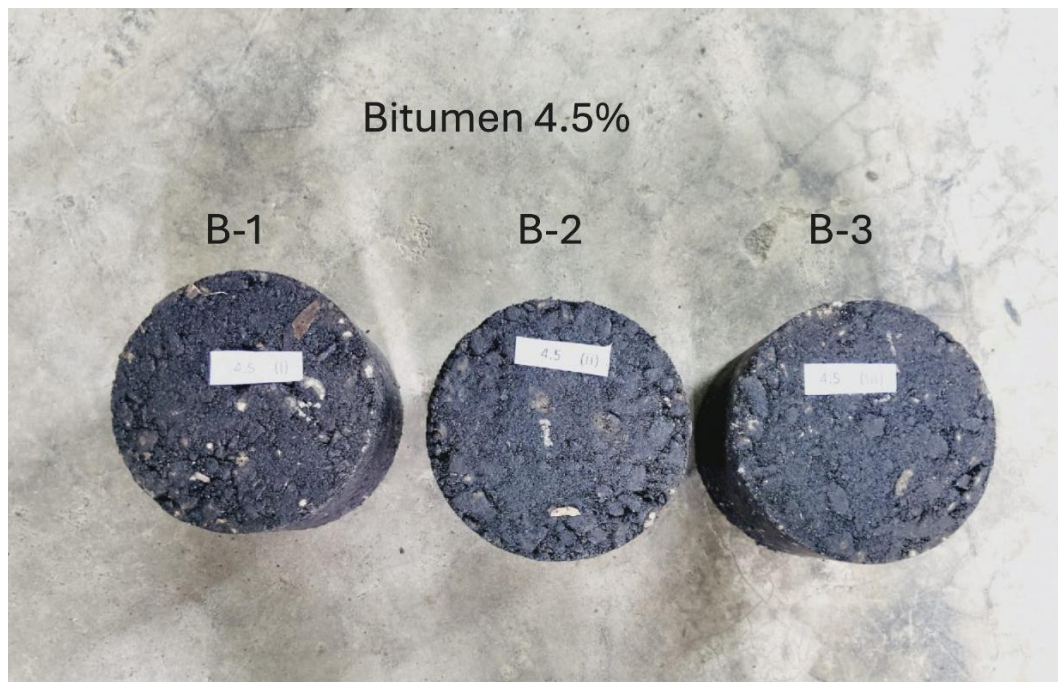


Figure 3.8 Marshall Mix Design Samples prepared with 4.5% bitumen

After demoulding, the specimens were placed in a water bath at 60°C for 30 minutes before conducting the Marshall test. The thickness was checked to ensure it was 63.5mm; otherwise, a correction factor was applied to the Marshall Stability. The average test values of the three samples were used for calculations.

3.5.2 Determination of Optimum Bitumen Content

The Marshall method is used to determine the optimum bitumen content. Samples with varying bitumen content are prepared and investigated for stability, air voids, voids in mineral aggregates, flow, and other properties.

3.6 Preparation Procedure for Waste LDPE Modified Mix and Marshall Tests

The procedure for incorporating waste LDPE into the asphalt mix is as follows.

- Waste LDPE in shredded small particle sizes is added into the mix, which comprises 2%, 4%, 6%, and 8% by weight of bitumen. This variation allows for assessing different levels of LDPE integration.

- Sasobit is added to all samples at a consistent 3% and 5% by weight of bitumen. (The optimum bitumen content is identified based on test results, ensuring a balance of strength, durability, and flexibility in the mix, which was found to be 4.7%. This is an analysis in Chapter 04.)

The blending percentages of LDPE, 60/70 Bitumen, and Sasobit are shown in Tables 3.4 and 3.5.

Table 3.4 Mixing Proportion of Bitumen, LDPE, and Sasobit 3%

LDPE adding % (by Bitumen)	0	2	4	6	8
LDPE	0	0.090	0.175	0.259	0.339
60/70 Bitumen	4.563	4.476	4.393	4.312	4.234
Sasobit (3% weigh by Bitumen)	0.137	0.134	0.132	0.129	0.127
Total	4.700	4.700	4.700	4.700	4.700

Table 3.5 Mixing Proportion of Bitumen, LDPE, and Sasobit 5%

LDPE adding % (by Bitumen)	0	2	4	6	8
LDPE	0	0.088	0.172	0.254	0.333
60/70 Bitumen	4.476	4.393	4.312	4.234	4.159
Sasobit (5% weigh by Bitumen)	0.224	0.219	0.216	0.212	0.208
Total	4.700	4.700	4.700	4.700	4.700

3.7 Testing of Properties of Marshall in LDPE-Sasobit Modified Asphalt Mixtures

3.7.1 Preparation of Sasobit-Modified Bitumen

Initially, 60/70 bitumen was heated to approximately 130°C in a mixing vessel. Sasobit was then added to the heated bitumen while stirring continuously to ensure uniform mixing. Figure 3.9 illustrates a bitumen mixing with 60/70 bitumen.



Figure 3.9 Sasobit Mixing with 60/70 Bitumen

3.7.2 Incorporation of LDPE

1. Wet Method

The waste LDPE was gradually introduced into the Sasobit-modified bitumen, maintaining the temperature at 130°C. The mixture was stirred continuously to ensure that the LDPE melted and dispersed evenly within the bitumen.

It was observed that the wet process faced challenges in achieving uniform mixing of LDPE with the Sasobit-modified bitumen.

2. Dry Method

Initially, the waste LDPE was pre-mixed with the aggregates. This aggregate mixture was then heated to approximately 140°C in an asphalt mixer to ensure adequate softening and coating of the LDPE onto the aggregate surfaces. Subsequently, Sasobit-modified bitumen was gradually added to the heated LDPE-aggregate mixture while stirring continuously to achieve a homogeneous blend. This method ensured uniform coating and mixing of all components.

The prepared asphalt samples were subjected to various laboratory tests to evaluate their mechanical properties. These evaluations aimed to assess the performance enhancements achieved through the incorporation of waste LDPE and Sasobit in the asphalt mixtures.

3.7.3 Marshall Stability Test

The Marshall Stability Test measured the maximum load-carrying capacity of an asphalt specimen and its deformation under load.

Procedure:

1. **Compaction:** The asphalt mixture was compacted in a mould using a hammer, applying 75 blows per side.
2. **Conditioning:** The compacted specimen was then immersed in a water bath maintained at 60°C for 30 to 40 minutes.
3. **Testing:** The specimen was placed in the Marshall testing machine. A vertical load was applied at a constant rate of 50 mm per minute until failure occurred. The maximum load (stability) was recorded in Newtons (N).
4. **Flow Measurement:** The deformation (flow) of the specimen at the point of maximum load was measured in millimeters (mm).

3.7.4 Testing of Additional Properties

1. Density - The mass of the specimen, including air and water, was determined. Based on these measurements, the bulk density was calculated.
2. Voids in Mineral Aggregate (VMA) - The VMA were computed using the bulk density and the aggregate content of the mixture.
3. Air Voids (Va) – The theoretical maximum specific gravity (G_{mm}) of the mixture was determined, and the Va were calculated using the bulk density and G_{mm}.

These properties were then compared with those of the conventional mix.

3.8 Cost Analysis Method

This study performed a cost analysis to evaluate the economic feasibility of using the WMA technology, incorporating waste LDPE and Sasobit, compared to the conventional HMA technology. The assessment focused on two primary cost drivers, material costs and energy savings resulting from reduced diesel consumption during the heating processes of bitumen and aggregates.

The initial part of the overall cost analysis compared the materials costs associated with the conventional HMA method and WMA method, incorporating waste LDPE and Sasobit.

Conventional Method: The material cost is expressed as aggregates and bitumen (without the inclusion of any additives or modifiers).

Warm Mix Method: The material cost consists of aggregates, bitumen, Sasobit, and waste LDPE.

3.8.1 Diesel Savings from Bitumen Heating

In this study, diesel consumption was measured during two distinct stages of the bitumen heating process to evaluate potential energy savings associated with WMA technology.

Stage 1: Heating from the Initial temperature to 130 °C. Diesel consumption was recorded until the bitumen temperature reached 130°C.

Stage 2: Continued heating from 130 °C, Diesel consumption was measured as the bitumen temperature increased from 130 °C to 150 °C.

The total diesel consumption for each stage was denoted as D_{130} and D_{150} respectively. The diesel savings per metric ton (MT) of asphalt produced were calculated using the following formula,

$$\text{Diesel Savings per MT} = \frac{D_{150} - D_{130}}{\text{Total Asphalt Production}}$$

Assuming stable diesel prices and consistent material availability throughout the analysis period, the diesel savings per MT were converted into financial savings using the average diesel price.

$$\text{Cost Savings per MT} = \text{Diesel Savings per MT} \times \text{Average Diesel Price (Rs/liter)}$$

3.8.2 Diesel Savings from aggregate heating

The diesel consumption data for aggregate heating was primarily collected over five months during the production of Wearing Course asphalt. During this period, the aggregate heating temperature was maintained at the standard operating temperature of 180 °C. To determine diesel consumption at a reduced aggregate heating temperature of 140 °C, a limited quantity of the Cutback type asphalt was produced within the same five-month period. For this production batch, the aggregate heating temperature was strictly maintained at 140 °C. This smaller-scale production provided controlled conditions to accurately measure diesel consumption exclusively at the lower heating temperature.

The diesel savings resulting from the reduction in aggregate heating temperature were calculated by comparing diesel consumption rates at 180 °C and 140 °C.

Determine Diesel Consumption Rate at 180 °C,

$$D_{180} = \frac{\text{Total diesel consumption for aggregate heating at 180 °C (liters)}}{\text{Total Asphalt Production (MT)}}$$

Determine Diesel Consumption Rate at 140 °C,

$$D_{140} = \frac{\text{Total diesel consumption for aggregate heating at 140 °C (liters)}}{\text{Total Asphalt Production (MT)}}$$

Calculation of Diesel Savings per MT,

$$\text{Diesel Savings per MT} = D_{180} - D_{140}$$

Assuming stable diesel prices and consistent material availability throughout the analysis period, the diesel savings per MT were converted into financial savings using the average diesel price.

Cost Savings per MT = Diesel Savings per MT x Average Diesel Price (Rs/liter)

CHAPTER 4. ANALYSIS OF EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Analysis of Properties of Aggregate Materials

The aggregate test results indicate that all measured properties fall within the acceptable limits, demonstrating good quality and suitability for construction use. The Aggregate Impact Value (AIV) is 23, well below the limit of 30, indicating good resistance to sudden impact loads. The Los Angeles Abrasion Value (LAAV) for both the 10-14 mm and 14-22 mm sizes is 39(GrB), which is just below the 40 limit, showing acceptable resistance to abrasion, although it is close to the upper limit and should be monitored. The Flakiness Index (FI) values of 26 for 10-14 mm and 21 for 14-22 mm are comfortably within the 35 limits, indicating a satisfactory aggregate shape for better interlock. Specific Gravity values for all sizes, both in dry (2.734-2.808) and apparent (2.789-2.831) states, fall within the acceptable range of 2.6-2.9, reflecting dense and sound aggregates. Water absorption values are all well below the 1 limit, indicating low porosity and good durability. Overall, the aggregates tested meet the required specifications, showing good strength, durability, shape, and low water absorption. Table 4.1 provides a summary of the test results along with the corresponding testing methods.

Table 4.1 Test Results of Aggregate Materials

Test Type	0-5 mm	5-10 mm	10-14 mm	14-22 mm	Specification Limits	Test Method
AIV	--	--	23	--	≤ 30	BS: 812
LAAV	--	--	39(GrB)	39(GrB)	≤ 40	ASTM C131
FI	--	--	26	21	≤ 35	BS: 812
SG (Dry)	2.734	2.761	2.781	2.805	2.6 – 2.9	
SG (App)	2.789	2.814	2.826	2.831		ASTM C
Water Abb.	0.81	0.68	0.48	0.39	≤ 1	127-77 & C 128-73

4.2 Analysis of Properties of Bitumen

The bitumen test results show that all measured properties comply with the specified requirements, indicating good quality and performance suitability. The penetration value at 25 °C is 64 (0.1 mm), within the 60-70 range, while the softening point is 48°C, meeting the 48-56°C limit, confirming the material’s appropriate consistency. The flash point is 332 °C, well above the minimum requirement of 232 °C, ensuring safety against ignition during handling. Kinematic viscosity at 135°C is 356cSt, indicating suitable flow characteristics. Ductility surpassing the minimum of 100 cm, showing high flexibility. All other property requirements are in an acceptable range. Overall, the bitumen meets all quality standards for road construction applications. Table 4.2 provides a summary of the test results along with the corresponding testing methods.

Table 4.2 Bitumen Test Results

Test	Test Method	Unit	Test Result	Specification Limit	
				Min.	Max.
Penetration 25°C 100g 5s	ASTM D5 /D 5M-13	0.1mm	64	60	70
Softening Point	ASTM D 36 – D 36M-14	°C	48.0	48	56
Flash Point	ASTM D 92-16b	°C	332	232	-
Kinematic Viscosity at 135°C	ASTM D 2170/ D 2170 M-10	cSt	356	-	-
Ductility 25°C 5cm/min	ASTM D 113-99	cm	>100	100	-
Specific gravity at 25°C	ASTM D 70 - 09		1.023	-	-
Solubility in trichloroethylene	ASTM D 2042-15	%Wt	99.2	99	-
Loss on heating for 5 hrs at 163°C					
1) Loss by weight percent	ASTM D 6 – D 6M- 95 (2018)	%Wt	0.61	-	1
2) Penetration after Loss on heating test percent of its original value	ASTM D 5/D 5M - 13	%	88	75	-

4.3 Blending of Aggregate Materials

The Sieve analysis is a fundamental process of classifying and characterizing aggregates used in asphalt mixtures. Understanding the distribution of particle sizes is essential for optimizing the mix design to achieve the desired properties, such as strength, durability, workability, and resistance to deformation and cracking. The results from the sieve analysis guide the proportioning of different aggregate sizes to create a homogeneous and high-performance asphalt mixture. The sieve analysis results for each aggregate size are presented in Table 4.3 and Figure 4.1. Also, the proportion of each aggregate material in the wearing course is shown in Table 4.4.

Table 4.3 Sieve Analysis Results of Aggregate Materials

Sieve Size in mm	Sample Passing %			
	HB#1	HB#2	HB#3	HB#4
28	100	100	100	100
20	100	100	100	97.6
10	100	100	95.2	1.1
5	100	65.3	0.4	0
2.36	92.2	3.4	0	0
1.18	80.4	0.8	0	0
0.600	61.1	0	0	0
0.300	41.3	0	0	0
0.150	28.9	0	0	0
0.075	14.2	0	0	0

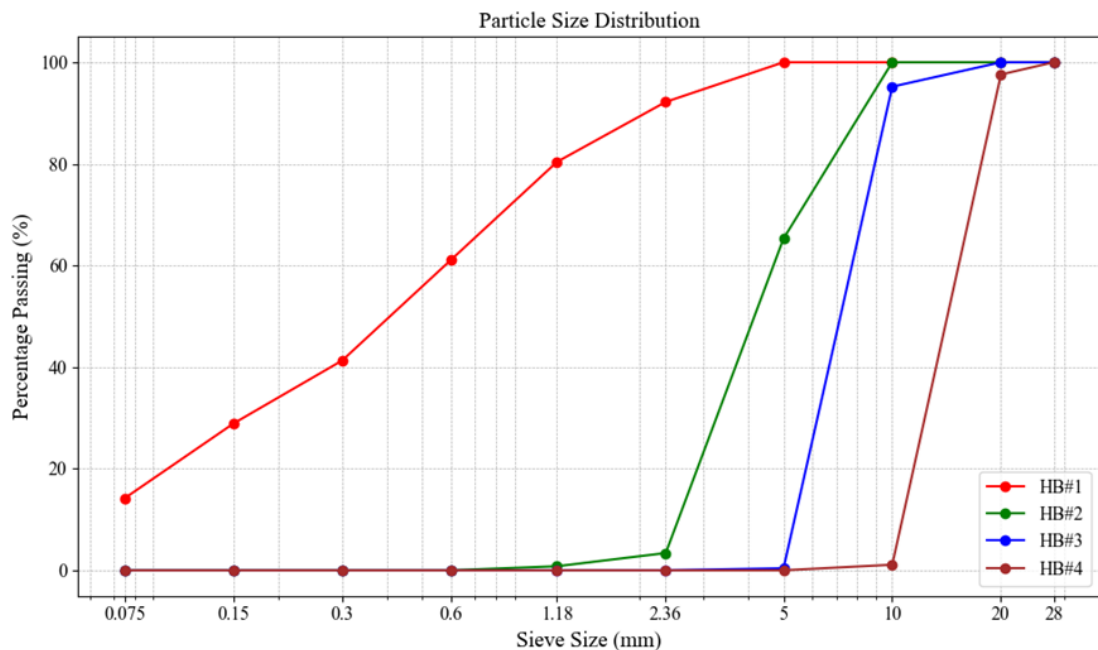


Figure 4.1 Particle Size Distribution of Aggregate Materials

Table 4.4 Proportion of each Aggregate Material from Proposed Mix

Aggregate Size	Proportion from proposed mix (%)
0 -5 mm	45
5 -10 mm	25
10 – 14 mm	15
14 – 19 mm	15
Sum	100

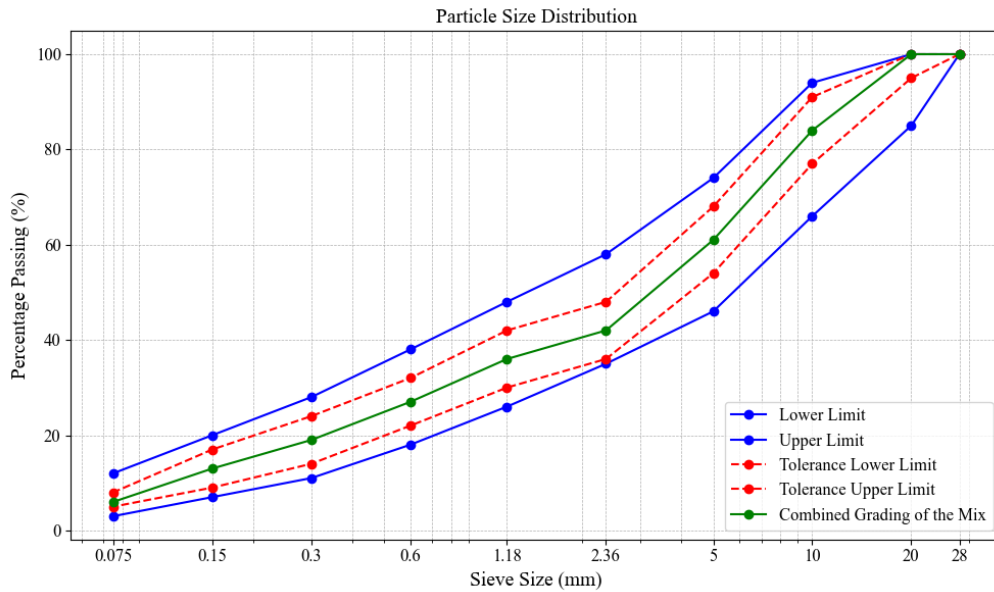


Figure 4.2 Gradation of Final Aggregate Mix

Table 4.5 Gradation of Proposed Mix with ICTAD Specification Limits

Sieve Size	Combined Grading	Specific Limit	
		Lower	Upper
28	100	100	100
20	100	85	100
10	84	66	94
5	61	46	74
2.28	42	35	58
1.18	36	26	48
0.600	27	18	38
0.300	19	11	28
0.150	13	7	20
0.075	6	3	12

The proposed aggregate grading curve, shown in Figure 4.2, satisfies the ICTAD specification for the asphalt wearing course. The combined gradation of the final aggregate mix, along with the ICTAD specification, is presented in Table 4.5.

4.4 Analysis of Marshall Mix Design for Conventional Asphalt Mix

As discussed in Chapter 03, 15 samples, each of 1200 g in weight, were prepared using five different bitumen contents (from 4-6% with 0.5% incremental) to obtain the Optimum Bitumen Content (OBC). Tables 4.6 and 4.7, along with Figures 4.3 to 4.6, summarize the Marshall Test results. Further details are presented in Appendix A.

Table 4.6 Test Results of the Marshall Mix Design

Bitumen % by total weight	Sample No	Correlation Stability (kN)	Flow (mm)	Bulk Density (g/cc)	Va (%)	Vb (%)	VMA (%)	VFB (%)
4.0	1	12.4	9.8	2.440	6.3	8.8	15.1	58.3
4.0	2	12.2	10.6	2.441	6.3	8.8	15.0	58.4
4.0	3	12.1	11.2	2.443	6.2	8.8	14.9	58.8
	Average	12.2	10.5	2.441	6.2	8.8	15.0	58.5
4.5	4	13.3	10.6	2.456	4.9	10.0	14.9	67.2
4.5	5	12.6	11.4	2.456	4.9	10.0	15.0	67.1
4.5	6	12.9	10.1	2.454	5.0	10.0	15.0	66.9
	Average	12.9	10.7	2.455	4.9	10.0	15.0	67.1
5.0	7	12.7	10.6	2.472	3.5	11.3	14.8	76.3
5.0	8	13.2	11.8	2.472	3.5	11.3	14.8	76.3
5.0	9	13.6	10.8	2.470	3.6	11.3	14.9	76.0
	Average	13.2	11.1	2.472	3.5	11.3	14.8	76.2
5.5	10	13.3	11.2	2.481	2.4	12.6	15.0	84.1
5.5	11	12.9	11.8	2.485	2.2	12.6	14.8	84.9
5.5	12	13.2	12.1	2.483	2.3	12.6	14.9	84.5
	Average	13.1	11.7	2.483	2.3	12.6	14.9	84.5
6.0	13	12.7	10.8	2.493	1.1	13.9	15.0	92.4
6.0	14	13.4	12.3	2.490	1.3	13.8	15.1	91.4
6.0	15	13.2	13.7	2.490	1.3	13.8	15.1	91.4
	Average	13.1	12.3	2.491	1.2	13.8	15.1	91.7

Table 4.7 Summary of the Marshall Mix Design

Bitumen % by total weight	Correlation Stability (kN)	Flow (mm)	Bulk Density (g/cc)	Va (%)	Vb (%)	VMA (%)	VFB (%)
4.0	12.2	10.5	2.441	6.2	8.8	15.0	58.5
4.5	12.9	10.7	2.455	4.9	10.0	15.0	67.1
5.0	13.2	11.1	2.472	3.5	11.3	14.8	76.2
5.5	13.1	11.7	2.483	2.3	12.6	14.9	84.5
6.0	13.1	12.3	2.491	1.2	13.8	15.1	91.7

4.4.1 Stability vs Bitumen Content

The relationship between stability and bitumen content is illustrated in Figure 4.3. The curve indicates that stability increases as the bitumen content increases from 4% to approximately 5%. The peak stability is observed to be around 5% bitumen content. After 5% bitumen content, stability shows a slight decrease.

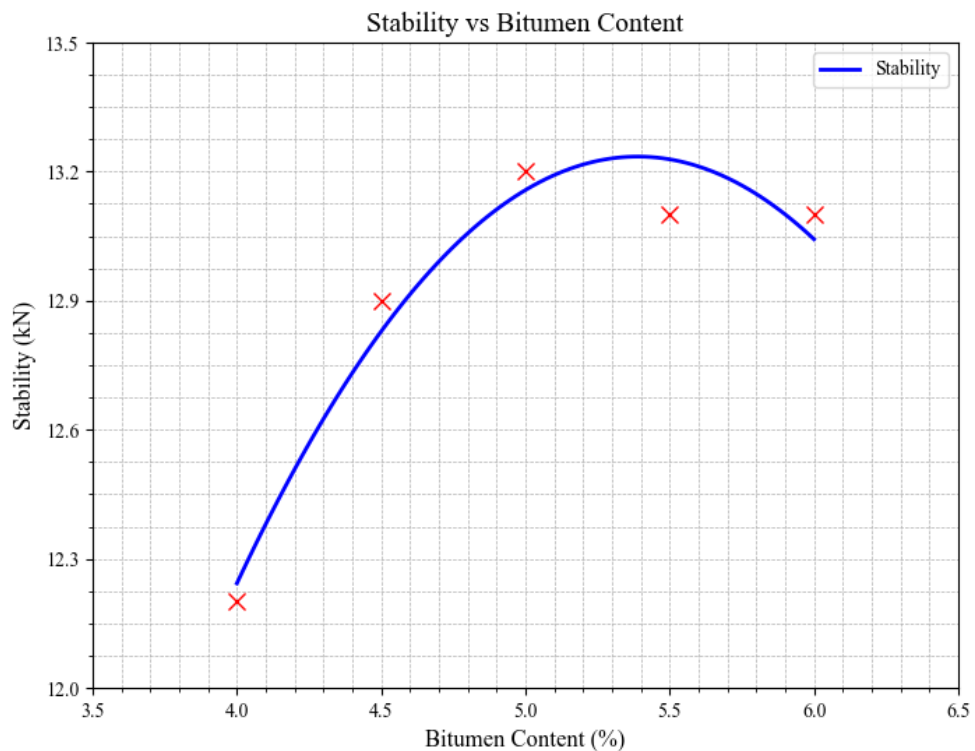


Figure 4.3 Stability vs Bitumen Content

4.4.2 Flow vs Bitumen Content

The relationship between Flow (0.25 mm) and Bitumen Content (%) is illustrated in Figure 4.4. The data points are marked in red, and a blue curve has been fitted to these points to show the trend. As the Bitumen Content increases from 4% to 6%, the flow increases from approximately 10.5 to 12.3. From Figure 4.4, an optimum range of Bitumen Content can be inferred where the Flow is within acceptable limits while balancing other factors like stability and voids. The range between 4.5% and 5.5% seems to offer a good balance, with a significant increase in Flow without an excessive jump.

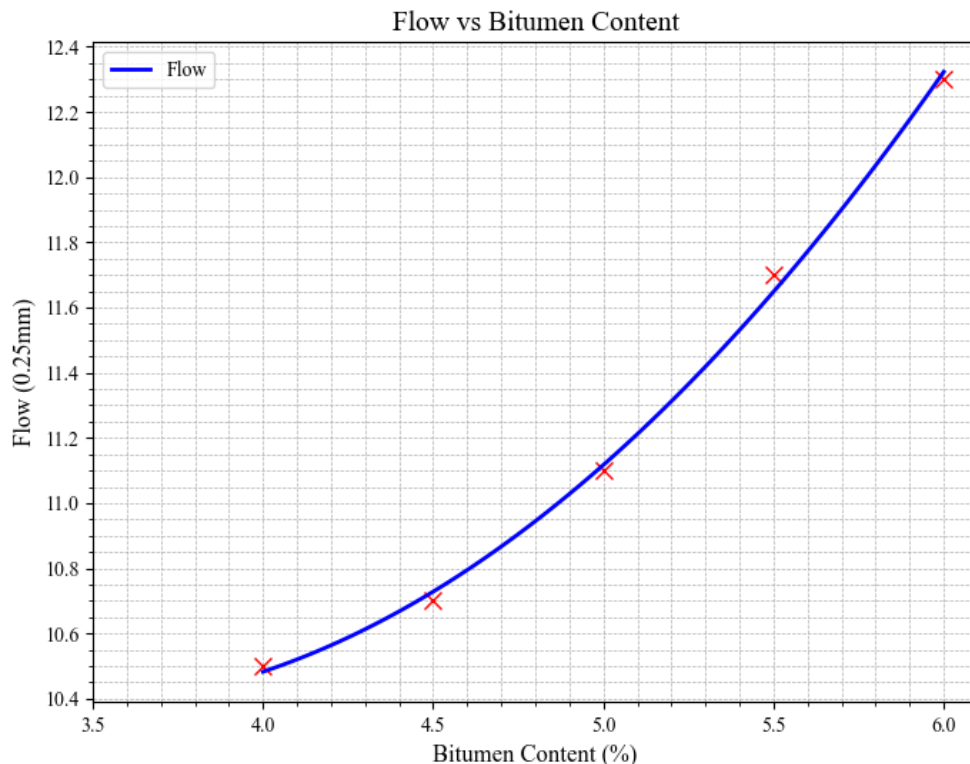


Figure 4.4 Flow vs Bitumen Content

4.4.3 Air Voids vs Bitumen Content

Figure 4.5 shows a clear negative correlation between Bitumen Content and Air Voids (Va). As the Bitumen Content increases from 4% to 6%, the Va decreases from approximately 6.2 to 1.2. From the figure, an optimal range of Bitumen Content can be inferred where Va is within acceptable limits while balancing other factors like

stability and workability. The range between 4.5% to 5.5% seems to offer a good balance, with a significant decrease in Va without an excessive drop.

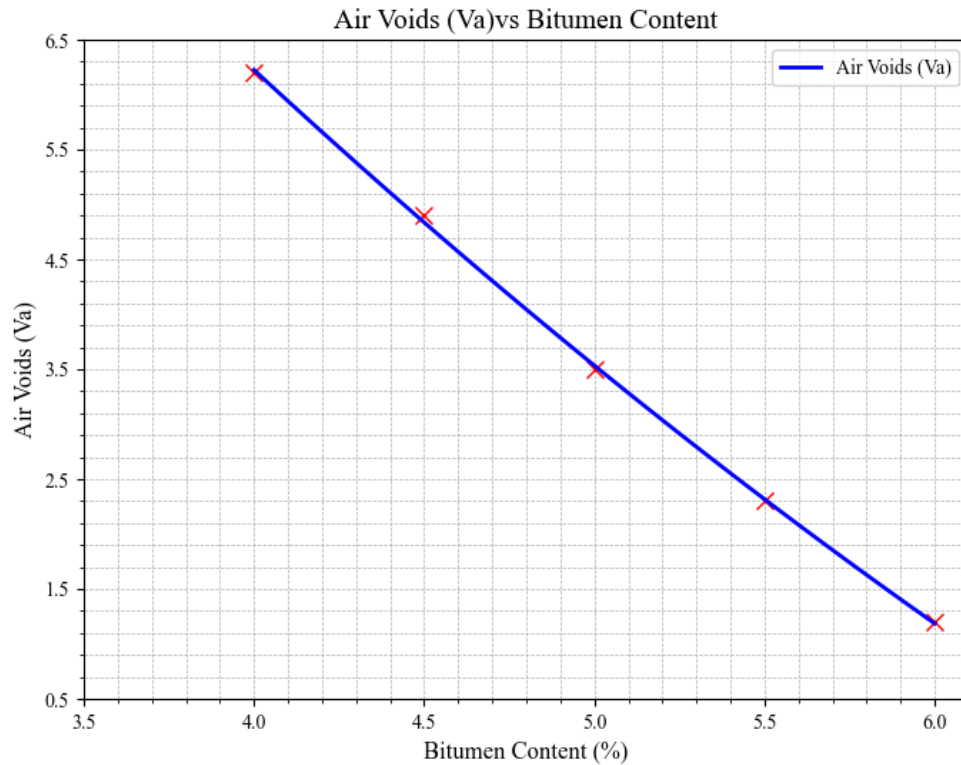


Figure 4.5 Air Voids vs Bitumen Content

4.4.4 Voids in Mineral Aggregate Vs Bitumen Content

Figure 4.6 indicates relatively stable Voids in Mineral Aggregate (VMA) with slight fluctuations as Bitumen Content increases. The VMA starts at 15 when the Bitumen Content is at 4% and remains around 15 up to 6% Bitumen Content, with minor variations. The stable VMA values suggest that the voids in the mineral aggregate are not highly sensitive to changes in Bitumen Content within this range. The range between 4.5% to 5.5% bitumen content appears optimal, balancing other factors like stability and flow.

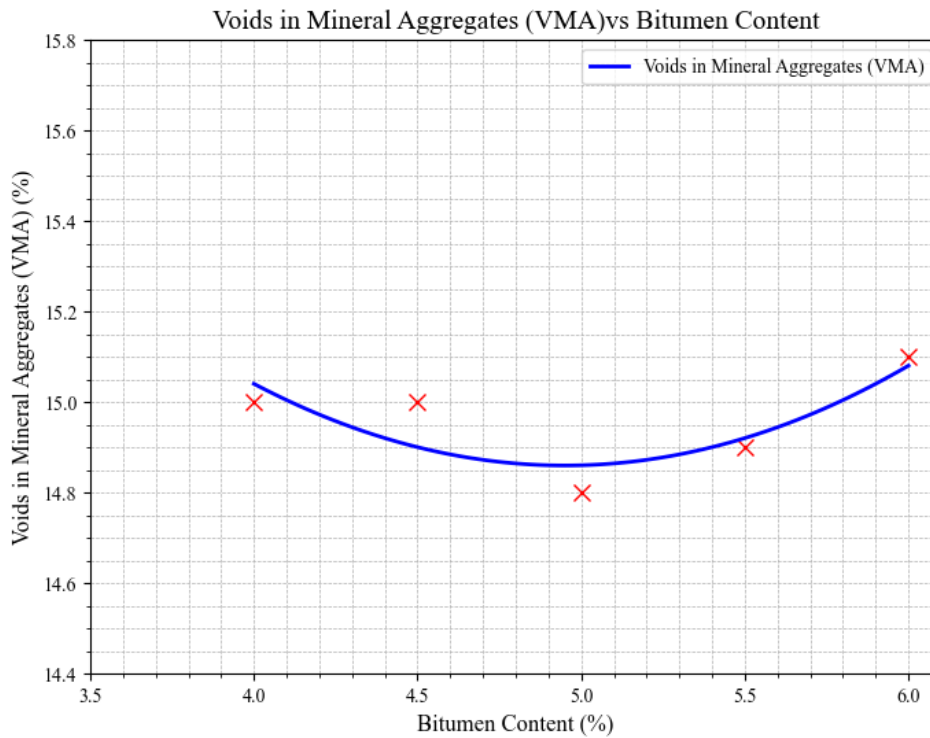


Figure 4.6 Voids in Mineral Aggregates vs Bitumen Content

4.4.5 Determination of Optimum Bitumen Content

Based on the Marshall test results, Table 4.8 presents the most appropriate bitumen content ranges for the mixture's performance. Since the Optimum Bitumen Content typically aims to balance stability, Va, VMA, and flow, the range of 4.5% to 5.2% is the most suitable. Considering the cost of Bitumen, 4.7% is selected as the Optimum Bitumen Content.

Table 4.8 Acceptable range of Bitumen Content vs Properties

Properties	Requirement	Allowed Bitumen Content-Range	
		Minimum	Maximum
Stability (kN)	8	4.0	6.0
Per cent Voids in Mineral Aggregate (VMA)	>13	4.0	6.0
Per cent Air Voids	3-5	4.5	5.2
Flow (0.25 mm)	8-16	4.0	6.0

At 4.7%, Va is approximately 4.3, which is within an acceptable range. At 4.7%, VMA is around 14.9, which is acceptable for the mix design. At 4.7%, Stability is around 13, close to its maximum value, indicating a strong mix. Flow increases with Bitumen Content, indicating better workability. At 4.7%, the Flow is around 10.8, within an acceptable range.

- Mix Design

Table 4.9 Summarized Mix Design

Aggregate Size	0 - 5 mm	5 - 10 mm	10 -14 mm	14 -22 mm
Blending Percentage	45	25	15	15
60/70 Bitumen for mixture (%)	4.7			

Aggregate Size Distribution: The larger percentage of smaller aggregates (0-5 mm) suggests that the mix aims for a dense, well-graded composition that can provide good compaction and stability. The blend of different sizes ensures that the voids between larger aggregates are filled by smaller ones, leading to a stronger and more durable mix. The 4.7% bitumen content is crucial for binding the aggregates together. Table 4.9 presents the summarized mix design.

4.5 Details analysis of the effect of adding Sasobit to 60/70 Grade Bitumen

Table 4.10 summarizes the test results of adding Sasobit to 60/70 grade Bitumen and its effect on penetration, softening point, and ductility.

Table 4.10 Effect of Bitumen Properties with adding Sasobit

Bitumen	Adding Sasobit by % of Bitumen weight	Penetration (0.1 mm)	Softening Point (°C)	Ductility (cm)
60/70 Grade	0	63	49.8	100
60/70 Grade	3	32	78	106
60/70 Grade	5	29	84	97

- Effect on Penetration

The penetration value decreases significantly from 63 to 29 with Sasobit 0% to 5%. This reduction in penetration suggests that Sasobit hardens the bitumen, enhancing its resistance to rutting and deformation under heavy loads, which is ideal for areas exposed to significant vehicle traffic or high temperatures.

- Effect on Softening Point

The softening point increases markedly with Sasobit addition, from 49.8°C to 84°C with Sasobit 0% to 5%. This means that bitumen can withstand higher temperatures before becoming soft. This makes it especially beneficial in warmer climates, where roads are exposed to intense sunlight and must withstand heat without deforming.

- Effect on Ductility

The ductility initially increases to 106 with the addition of 3% Sasobit, indicating improved flexibility, but then slightly decreases to 97 with the addition of 5% Sasobit, although it remains within a reasonable range.

4.6 Analysis of LDPE Mixing Processes

The experimental results obtained from the mixing processes of LDPE with Sasobit and Bitumen are presented. The aim is to determine the effectiveness of two mixing methods: wet and dry.

4.6.1 Wet Process

LDPE shopping bags are mixed directly with the Sasobit modified Bitumen mixer in the wet process at a higher temperature. During this process, it was observed that the LDPE did not blend well with the Sasobit-modified Bitumen mixture. The high-temperature conditions led to incomplete mixing, likely due to the physical and chemical incompatibilities between the LDPE and the mixer components. Figure 4.7 illustrates the results of the wet process, highlighting the uneven distribution and poor incorporation of LDPE within the mixture.



Figure 4.7 LDPE Mixing with Sasobit-modified Bitumen mixture

4.6.2 Dry Process

Conversely, the dry process involves blending the LDPE shopping bags with hot aggregates before adding the Sasobit modified Bitumen. This method proved more effective, as the LDPE was mixed thoroughly and uniformly within the mixture. The process allowed the LDPE to coat the hot aggregate, enhancing compatibility when the Sasobit-modified Bitumen mixer was subsequently introduced. Given the successful outcome of the dry process, further laboratory investigations were conducted using this method as the baseline for testing other parameters and properties of the LDPE-modified bituminous mixtures.

4.7 Analysis of Marshall Properties of LDPE, Sasobit Modified Asphalt Mixture

The Marshall properties for LDPE and Sasobit modified asphalt are examined to explore the impact of varying percentages of waste LDPE on performance characterization parameters. Laboratory investigations were carried out to investigate the influence of waste LDPE on certain properties like Stability, Flow, Va, VMA, and Bulk Specific Gravity. Figure 4.8 illustrates the Marshall mix design samples prepared with sasobit 3%, LDPE 6%.

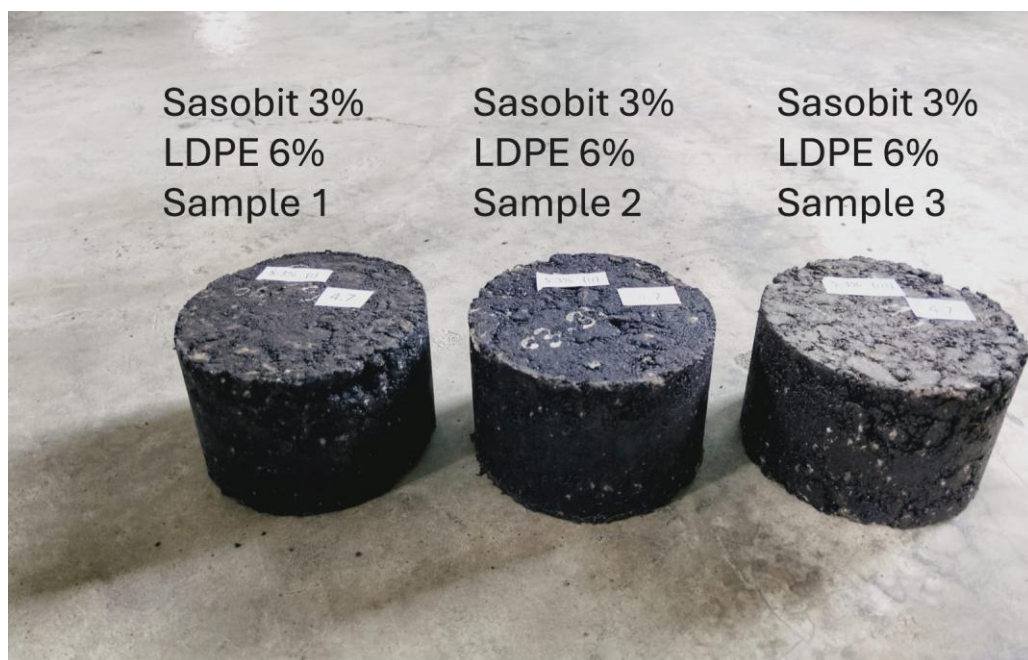


Figure 4.8 Marshall Core Samples

4.7.1 Analysis of the Effect of Waste LDPE% on Stability

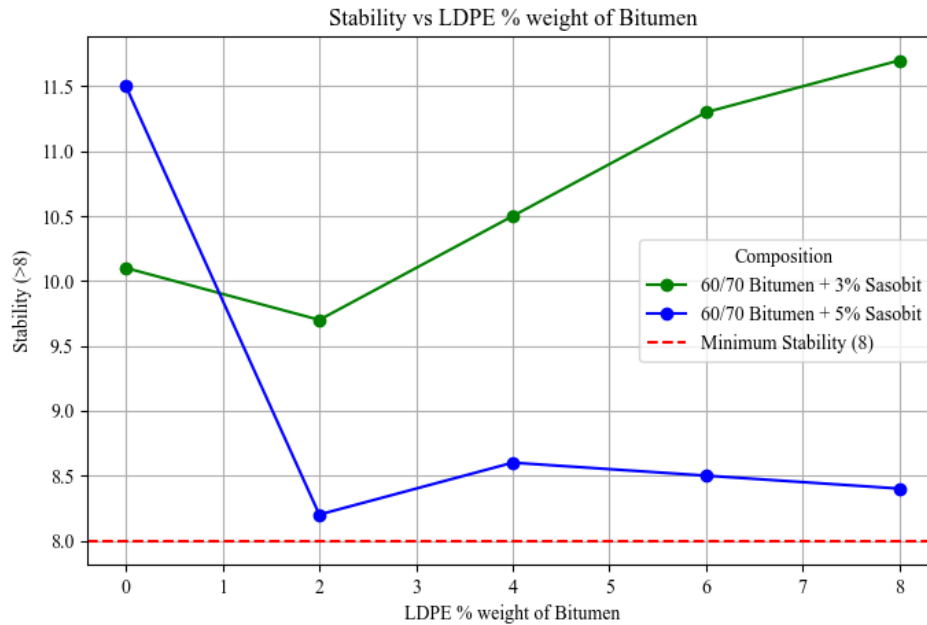


Figure 4.9 Stability vs LDPE % weight of Bitumen

Figure 4.9 displays how stability values change with varying LDPE percentages in bitumen modified with 3% and 5% Sasobit.

For the 3% Sasobit mixture, stability improves as the LDPE content increases beyond the minimum required level of 8, which is suitable for road construction. However, for the 5% Sasobit mixture, stability remains below 9 until a low percentage of LDPE is added, indicating that the performance of the mixture degrades with an increased amount of LDPE, particularly at higher percentages.

The stability of the 3% Sasobit mixture improves with the addition of LDPE content, but this effect does not occur for the 5% Sasobit mixture. As the Sasobit content increases to 5%, stability decreases with the addition of more LDPE, resulting in values closer to the minimum required stability for pavement mixes.

According to this graph, the bitumen mixture containing 3% Sasobit and an optimal LDPE content of about 4–6% shows the highest stability, exceeding the minimum required stability. However, caution should be exercised when adjusting the LDPE content in a 5% Sasobit mixture to ensure its applicability in the high-performance area.

4.7.2 Analysis of the Effect of Waste LDPE% on Air Voids

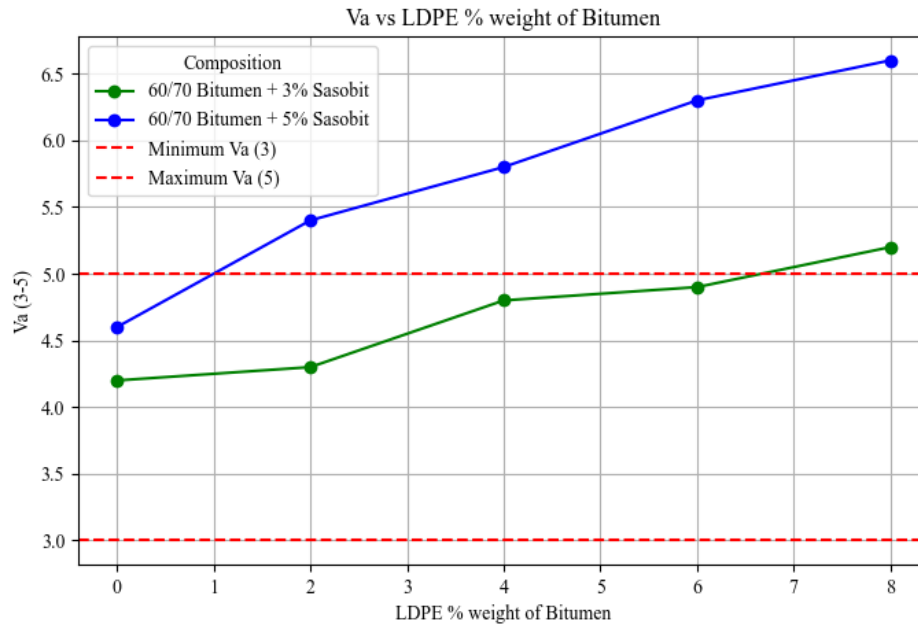


Figure 4.10 Air Voids vs LDPE% weight of Bitumen

Figure 4.10 displays how Va values change with varying LDPE percentages in bitumen modified with 3% and 5% Sasobit. For the 3% Sasobit mixture, the Va values gradually increase from 0% to 8%. At 8% LDPE, the Va value exceeds the acceptable range. This indicates that while this composition maintains a desirable Va range up to 6%, it remains stable for mixtures requiring controlled air voids.

For the 5% Sasobit mixture, adding LDPE (from 2% to 8%) increases Va beyond the acceptable range. This suggests that this combination may result in excessive air voids, which could compromise the material's structural integrity.

For the 3% Sasobit mixture, the increase in Va with higher LDPE content improves the mixture's workability and durability, making it suitable for applications where controlled Va are essential for high-quality road performance. However, for the 5% Sasobit mixture, it is more sensitive to the addition of LDPE, which may lead to excessive air voids. Exceeding the maximum Va of 5 can affect the mixture's compaction and reduce its durability in pavement applications.

The mixture of 3% Sasobit with 4-6% LDPE provides the most balanced composition, keeping Va within the acceptable range (3 to 5).

4.7.3 Analysis of the Effect of Waste LDPE% on VMA

Figure 4.11 displays how VMA values change with varying LDPE percentages in bitumen modified with 3% and 5% Sasobit.

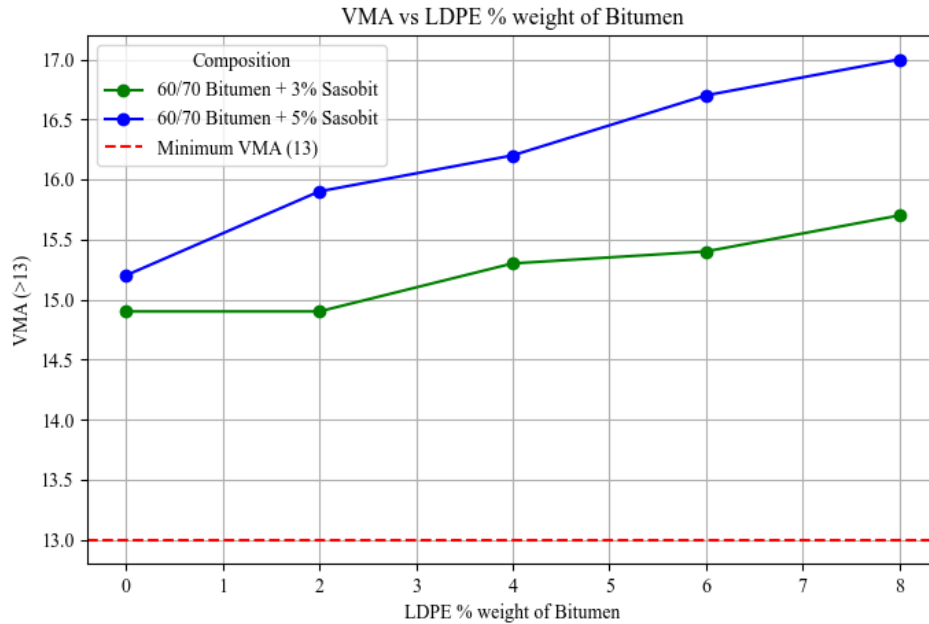


Figure 4.11 Voids in Mineral Aggregate vs LDPE% weight of Bitumen

For the 3% Sasobit mixture, the VMA gradually increases from 14.9 in 0% LDPE to a maximum 15.7 in 8% LDPE. The VMA remains well above the minimum threshold (13) throughout the range of LDPE percentages.

For the 5% Sasobit mixture, the VMA shows a more significant increase as LDPE content rises, starting at 15.2 and climbing to 17 at 8% LDPE.

Increasing LDPE improves the VMA for both mixtures, indicating that LDPE helps increase the void space and provides better compaction properties. However, in the 5% Sasobit mixture, the rise in VMA is more noticeable and exceeding the desired range can lead to a mixture that has too much void space, potentially weakening the overall structure.

The 3% Sasobit mixture with 2-8% LDPE offers the best balance of void space and compaction, keeping the VMA above the minimum threshold without excessive increases. For the 5% Sasobit mixture, the optimum range would be between 2-6% LDPE to avoid excessive voids and maintain structural integrity.

4.7.4 Analysis of the Effect of Waste LDPE% on Flow

Figure 4.12 shows the Flow values change with varying the LDPE% in bitumen modified with 3% and 5% Sasobit.

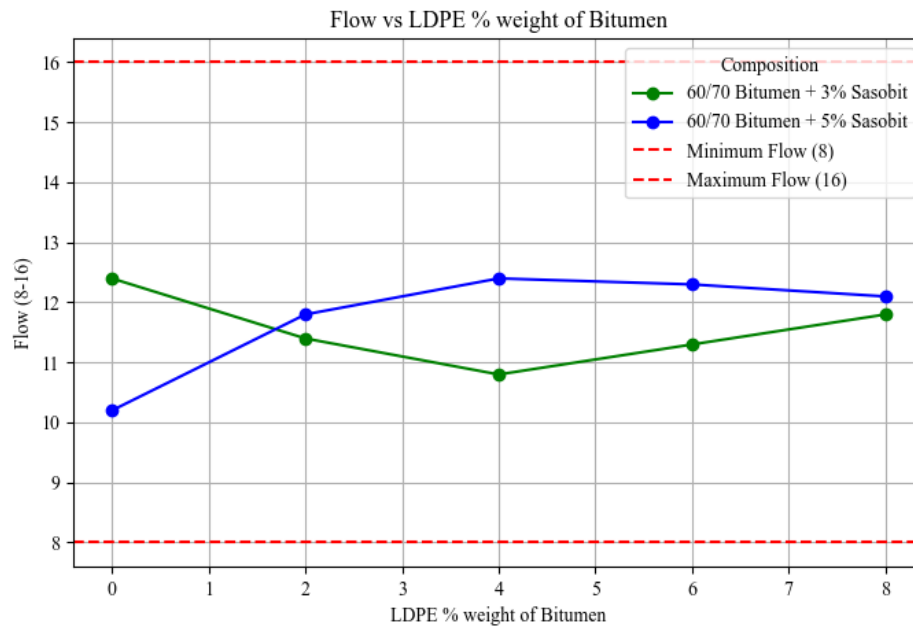


Figure 4.12 Flow vs LDPE % weight of Bitumen

For the 3% Sasobit mixture, there is a slight decrease in Flow with an increasing LDPE, which may imply a small increase in stiffness. However, it remains within the acceptable range and shows overall stability.

For the 5% Sasobit mixture, there is a slight increase in Flow with additional LDPE, which could indicate slightly more flexibility, especially at higher LDPE levels. The values remain within the desired range, suggesting good performance characteristics.

LDPE content improves the mixture's workability and flow in both mixtures. Both mixtures perform optimally with the LDPE percentage of 2-6%, ensuring stability and controlled flow, while providing the necessary strength and workability without exceeding the desired properties for road construction.

4.7.5 Analysis of the Effect of Waste LDPE% on Bulk Specific Gravity

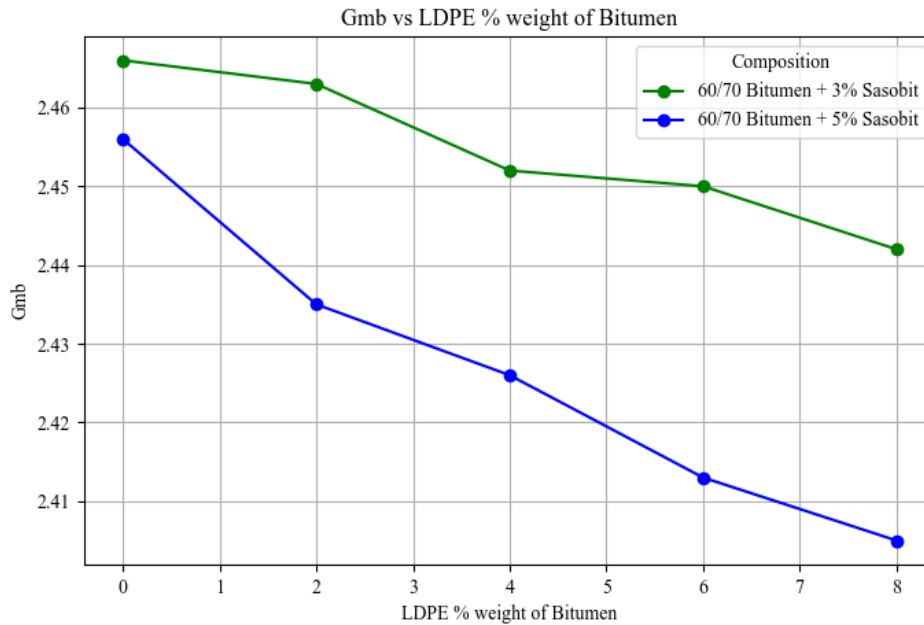


Figure 4.13 Bulk Specific Gravity vs LDPE % weight of Bitumen

Figure 4.13 illustrates the Bulk specific gravity values change with carrying LDPE percentages in bitumen modified with 3% and 5% Sasobit. For the 3% Sasobit Mixture, the Gmb values for this composition decrease gradually as LDPE content increases. Starting at 2.466 for 0% LDPE, Gmb decreases slightly to 2.442 at 8% LDPE. This decrease indicates that as more LDPE is added, the density of the mixture is marginally reduced, but the change is relatively minor.

For the 5% Sasobit Mixture, the Gmb values also decrease with increasing LDPE content, but at a slightly faster rate compared to the 3% Sasobit mixture. The initial Gmb at 0% LDPE is 2.456, which drops to 2.405 at 8% LDPE. The steeper decline suggests that adding more LDPE to the 5% Sasobit mixture affects the density more significantly than with the 3% Sasobit mixture.

The reduction in Gmb with higher LDPE content for both compositions may indicate an increase in void space within the mix, resulting in a lighter structure. This trend could potentially affect the mixture's strength and stiffness.

Both mixtures perform optimally with LDPE content of 2-6%. This range ensures a balance between workability, compaction, and density, providing the necessary strength and durability for road construction without compromising the mixture's performance.

4.7.6 Analysis of Optimum Sasobit%

1. With 3% Sasobit modified bitumen mixture

At 8% LDPE, this composition satisfies the Stability, Flow, and VMA requirements, but the Va value exceeds the upper acceptable limit, which could lead to reduced durability. All other LDPE% levels (0%, 2%, 4%, and 6%) satisfy the Va, VMA, Stability, and Flow thresholds. Bulk specific gravity decreases slightly with an increase in the LDPE content, but in all cases, the values are within the acceptable limits. In general, this composition consistently maintains properties in the desired range, which is indicative of good overall performance and stability at all levels of LDPE.

2. With 5% Sasobit modified bitumen mixture

At 0% LDPE, this composition meets all thresholds. However, at 2% LDPE and above, Va values exceed the upper limit of 5%, indicating higher air voids, which could lead to reduced durability. Despite this, VMA, Stability, and Flow remain within acceptable ranges. Gmb decreases more noticeably with higher LDPE content, which could affect density and compaction quality. LDPE levels of 2% and higher may not be optimal due to excessive air voids.

The optimal composition is 3% Sasobit modified Bitumen mixture at 0%, 2%, 4%, and 6% LDPE levels, as it consistently meets all Marshall property thresholds, including Va, VMA, Stability, and Flow. This combination offers durability, stability, and density, making it suitable for a high-performance asphalt mix.

4.8 Analysis of Cost

4.8.1 Analysis of Material Cost

Table 4.11 Mixing Proportion for Preparing 1 MT of Asphalt

Aggregate Size	0 - 5 mm	5 - 10 mm	10 -14 mm	14 -22 mm
Blending Qty for 1MT (kg)	428.85	238.25	142.95	142.95
60/70 Bitumen (kg)	47.00			

Table 4.11 illustrates the mixing proportions used to produce 1 MT of asphalt. This analysis was based on the material cost required to produce 1 MT of asphalt mix across all the different compositions. The cost of each composition was calculated by multiplying the required quantity of each material by its unit price. Since aggregate quantities remained the same in all mixes, only bitumen, Sasobit, and LDPE were included in the cost comparison.

This comparison is conducted between HMA and the WMA, in several different mixtures that are produced using three types of WMA additives: bitumen, Sasobit, and LDPE to achieve cost reductions.

Table 4.12 illustrates the total material costs for producing 1 MT of asphalt for each method, excluding the cost of aggregates. The conventional HMA is a mixture of 60/70 bitumen at 47 kg per metric ton (MT) with a unit cost of Rs 179.99. The total material cost for 1 MT of HMA is Rs 8,459.53. This serves as an initial standard for comparing WMA mixtures, which incorporate Sasobit and LDPE to reduce the bitumen content and material costs.

WMA with 0% LDPE: In this mix, the bitumen quantity is reduced to 45.63 kg, complemented by 1.37 kg of Sasobit at 3% by weight, which serves as a warm mix additive, lowering the temperature needed for mixing. Sasobit costs Rs 930.00 per kg, resulting in an additional cost of Rs 1,274.10. The total cost for this WMA mix increases to Rs 9,487.04, which is higher than HMA due to the significant expense of Sasobit. However, this mix facilitates lower energy consumption during production, potentially offsetting higher initial material costs.

Table 4.12 Total Material Cost (Except Aggregate Cost)

Asphalt mix	Material Type	Required Qty for 1MT (kg)	Unit Price (Rs)	Amount (Rs)	Grand Amount (Rs)
Hot Mix	Bitumen 60/70	47	179.99	8,459.53	8,459.53
Warm Mix	Bitumen 60/70	45.63	179.99	8,212.94	9,487.04
	Sasobit 3%	1.37	930.00	1,274.10	
	LDPE 0%	0	10.00	0.00	
Warm Mix	Bitumen 60/70	44.76	179.99	8,056.35	9,311.55
	Sasobit 3%	1.34	930.00	1,246.20	
	LDPE 2%	0.90	10.00	9.00	
Warm Mix	Bitumen 60/70	43.93	179.99	7,906.96	9,152.06
	Sasobit 3%	1.32	930.00	1,227.60	
	LDPE 4%	1.75	10.00	17.50	
Warm Mix	Bitumen 60/70	43.12	179.99	7,761.17	8,986.77
	Sasobit 3%	1.29	930.00	1,199.70	
	LDPE 6%	2.59	10.00	25.90	

WMA with 2% LDPE: Here, the bitumen content further reduces to 44.76 kg, with 1.34 kg of Sasobit and the addition of 0.90 kg of LDPE, a recycled material costing Rs 10 per kg. The inclusion of LDPE marginally lowers the cost to Rs 9,311.55 compared

to the previous WMA variant. By substituting a portion of bitumen with LDPE, this mix maintains comparable performance characteristics while offering cost reductions.

WMA with 4% LDPE: In this variant, bitumen content decreases to 43.93 kg, with the addition of 1.32 kg of Sasobit and 1.75 kg of LDPE. The total material cost for this mix is Rs 9,152.06, representing a further reduction from the 2% LDPE variant. This cost reduction results from substituting a more significant portion of bitumen with the low-cost LDPE, balancing Sasobit's expense.

WMA with 6% LDPE (Additional Reduction in Bitumen): This final WMA variant minimizes bitumen content to 43.12 kg, complemented by 1.29 kg of Sasobit and 2.59 kg of LDPE, resulting in a total cost of Rs 8,986.77. This configuration demonstrates the lowest material cost across all mixes, as the combined LDPE and Sasobit additions permit a substantial bitumen reduction.

While WMA formulations with Sasobit and LDPE increase the initial material costs compared to HMA, specific configurations with higher LDPE percentages and lower bitumen content achieve cost reductions. The mix with 6% LDPE and 3% Sasobit yields the most economical solution at Rs 8,986.77 per MT. This balance of reduced bitumen content, supplemented by cost-effective LDPE and Sasobit, represents a sustainable, cost-efficient alternative to HMA. These findings can guide asphalt mix design decisions, especially in contexts aiming to reduce costs and environmental impact by leveraging recycled materials like LDPE.

The results indicate that using Sasobit and LDPE as additives in WMA reduces the required bitumen content, which translates into both cost and environmental benefits. While the initial addition of Sasobit alone increased the cost compared to HMA, combining Sasobit with LDPE in increasing percentages resulted in progressive cost reductions. This trend suggests that LDPE could offset some of the cost increases associated with Sasobit, offering a more cost-effective WMA formulation as LDPE content rises.

4.8.2 Analysis of Diesel Consumption at the Keragala Asphalt Plant

This section analyses the financial implications of reducing heating temperatures in asphalt production at the Keragala Asphalt Plant. It assesses the potential cost savings from temperature adjustments by examining diesel consumption costs associated with bitumen and aggregate heating. The analysis is based on diesel consumption data from June to October 2023, comparing actual savings when temperatures are reduced.

The analysis aims to quantify the fuel efficiency and cost-effectiveness of the WMA approach relative to HMA, providing valuable insights toward energy optimization at the plant.

To accurately estimate financial savings, we need to determine the average cost of diesel per liter. Table 4.13 shows historical diesel price data for the period from June to October 2023. Further details are available in Appendix B.

Table 4.13 Historical Diesel Cost from June 2023 to October 2023 [53]

Month	Diesel Price (Rs)
June	310.00
July	308.00
August	306.00
September	341.00
October	351.00
Average Diesel Price	323.20

For this study, assume a diesel price of Rs 323.20 per liter. This price will be the basis for calculating the financial savings achieved through reduced diesel consumption.

- **Cost Savings from Bitumen Heating Reduction (150°C to 130°C)**

The bitumen heating process maintains a temperature of 150°C using diesel. However, diesel is saved by lowering the temperature to 130°C. The temperature was reduced, and savings were observed over five months. Table 4.14 summarizes the total diesel savings for the period from June to October 2023.

Table 4.14 Diesel Consumption for Bitumen Heating

Month	Total Production (MT)	Diesel Consumption Bitumen heating to 150° C (Liters)	Diesel Consumption Bitumen heating to 130° C (Liters)
June	2,157.37	6,432.14	5,735.24
July	754.08	2,989.40	2,571.27
August	1,712.30	4,338.35	3,566.17
September	1,413.22	3,449.98	2,992.63
October	1,972.35	4,001.79	3,561.04
Total	8009.32	21,211.66	18,426.35

Total Diesel Consumption (D_{130}) = 18,426.35 liters

Total Diesel Consumption (D_{150}) = 21,211.66 liters

Total Diesel Savings = 21,211.66 - 18,426.35 = 2,785.31 liters

The total diesel savings from lowering the bitumen heating temperature across all months is 2,785.31 liters. which equates to a percentage saving of about 13.13%.

Calculation of Diesel Savings per MT:

$$\text{Diesel Savings per MT} = \frac{2,785.31}{8009.32} = 0.35 \text{ liters}$$

Using the diesel price, the financial savings from reducing the bitumen heating temperature and calculated as follows:

$$\text{Cost Savings per MT} = 0.35 \times 323.20 = \text{LKR } 113.12$$

This results in total financial savings of approximately Rs. 113.12 per MT from reducing the bitumen heating temperature.

- **Cost Savings from Aggregate Heating Reduction (180°C to 140°C)**

Aggregate heating requires significantly higher temperatures and, therefore, consumes more diesel than bitumen heating. The total diesel consumption for producing the wearing course from June to October 2023 is shown in Table 4.15. In this process, diesel is used to heat the aggregate to a temperature of 180°C. In contrast, the total diesel consumption for producing the cutback during the same period is shown in Table 4.16. The cutback is used for road maintenance works, but it does not require heating to as high a temperature, only up to 140°C.

Table 4.15 Diesel Consumption for Aggregate Heating for Wearing Course

Month	Total Production (MT)	Diesel Consumption (Liters)
June	2,103.60	11,052.08
July	694.79	3,541.15
August	1,677.68	7,789.69
September	1,280.15	9,412.53
October	1,883.49	15,005.21
Total	7,639.71	46,800.66

Table 4.16 Diesel Consumption for Aggregate Heating for Cutback

Month	Total Production (MT)	Diesel Consumption (Liters)
June	53.77	214.78
July	59.29	236.45
August	34.62	163.96
September	133.07	641.49
October	88.86	510.00
Total	369.61	1,766.68

Considering the Production Process of Wearing Course (Aggregate heating up to 180° C)

$$\text{Diesel consumption per MT} = \frac{46,800.66}{7,639.71} = 6.13 \text{ liters}$$

Considering the Production Process of Cutback (Aggregate heating up to 140° C)

$$\text{Diesel consumption per MT} = \frac{1,766.88}{369.61} = 4.78 \text{ liters}$$

$$\text{Diesel Savings per MT} = 6.13 \text{ liters} - 4.78 \text{ liters} = 1.35 \text{ liters}$$

Using the diesel price, the financial savings for aggregate heating reduction are calculated as follows:

$$\text{Cost Savings per MT} = 1.35 \times 323.20 = \text{LKR } 436.32$$

This results in total financial savings of approximately Rs. 436.32 per MT from reducing the aggregate heating temperature.

- **Comparative Cost Savings Analysis**

A comparison of total cost savings for both methods is summarized below:

$$\text{Total Savings MT} = \text{Savings in Aggregate Heating} + \text{Savings in Bitumen Heating}$$

$$\text{Total Cost Savings per MT} = \text{LKR } 436.32 + \text{LKR } 113.12$$

$$\text{Total Cost Savings per MT} = \text{LKR } 549.44$$

- **Comparison of Total Production Cost**

Table 4.17 illustrates the asphalt costs for producing 1 MT of asphalt for each mix type, along with the corresponding savings and adjusted costs after applying diesel

savings.

Table 4.17 Total Production Cost per MT (except Aggregate)

Asphalt Mix	Description	Binder Cost per MT	Savings per MT	Amount of after-cost savings (Rs)
HMA	Bitumen 60/70	8,459.53	-	8,459.53
WMA	Bitumen 60/70 + Sasobit 3% + LDPE 0%	9,487.04	549.44	8,937.60
WMA	Bitumen 60/70 + Sasobit 3% + LDPE 2%	9,311.55	549.44	8,762.11
WMA	Bitumen 60/70 + Sasobit 3% + LDPE 4%	9,152.06	549.44	8,602.62
WMA	Bitumen 60/70 + Sasobit 3% + LDPE 6%	8,986.77	549.44	8,437.33

4.9 Summary of the Results

4.9.1 Stability

The stability of the mixtures is one of the main properties used to evaluate their resistance to deformation under load. The results showed that mixtures with 3% Sasobit exhibited increasing stability as the proportion of LDPE increased, with the highest stability value recorded at 8% LDPE (11.7 kN). This indicates that adding LDPE directly enhances rigidity, leading to better stability. In contrast, as the LDPE content increased in mixtures containing 5% Sasobit, the stability decreased. The lowest stability value of 8.2 kN was observed at 2% LDPE, which is believed to occur because Sasobit softens the mixture's matrix interface, reducing its resistance to deformation under load [54].

Adding LDPE improves the bitumen's stiffness, making the mixture more stable, especially at lower Sasobit contents. At higher Sasobit levels, however, the stiffening effect of Sasobit may outweigh that of LDPE, causing overall stability to decrease.

4.9.2 Air Voids

Air voids are critical for the compatibility and permeability of bituminous mixtures. The air voids varied between 4.3% and 4.9%, remaining within the acceptable limits of 3-5% for mixtures with 3% Sasobit (at 2%, 4%, and 6% LDPE). In contrast, the air voids increased in mixtures with 5% Sasobit (at higher LDPE contents), ranging between 5.4% and 6.6%. These changes in air voids were influenced by the higher doses of Sasobit, which affected compatibility, especially when LDPE content was high.

High air voids can reduce the mixture's durability and strength, making it more susceptible to moisture damage. Maintaining air voids within optimal limits ensures proper binder coating and reduces the risk of long-term degradation.

4.9.3 Voids in Mineral Aggregate

VMA is crucial for proper binder coating and the retention of sufficient air void contents in this type of mixture. Sasobit contents were above the minimum requirement of 13% for VMAs. The bulk VMA ranged from 14.9% to 15.7% for the 3% Sasobit mixtures and 15.2% to 17% for the 5% Sasobit mixtures. A higher LDPE content creates more void space for binders to fill, which is beneficial because it ensures proper binder coverage, as indicated by the increased VMA.

Excessive VMA may reduce the mixture's stiffness, leading to deformation under traffic stress. Therefore, VMA control is necessary to ensure proper binder availability without compromising the mixture's stiffness.

4.9.4 Bulk Density

Bulk density is an important parameter that indicates the compactness of a mixture. Both Sasobit contents show a decrease in bulk density with increasing LDPE content, as evidenced by the results. For instance, the bulk density of mixtures with 3% Sasobit was reduced from 2.466 g/cm³ to 2.442 g/cm³, and that for mixtures with 5% Sasobit decreased from 2.456 g/cm³ to 2.405 g/cm³. This is due to the lower density of LDPE compared to bitumen.

An increase in the content of LDPE will decrease bulk density, affecting the mixture's compaction. This will lead to increased air voids and a reduction in strength. Proper compaction during construction is essential to ensure optimal mixture density.

4.9.5 Flow

Flow values indicate how flexible mixture is when weight is applied. The flow values of mixtures containing 3% Sasobit were between 10.8 mm and 12.4 mm, while those with 5% Sasobit ranged from 10.2 mm to 12.4 mm. Flow values did not change significantly in different LDPE concentrations, indicating that both Sasobit and LDPE contribute to the flexibility of the mixture.

A higher amount of LDPE makes the mixture more flexible, which is desirable for some applications. However, it is important to ensure that the flow values remain within the appropriate range, for instance, excessive flow could reduce stability and increase the risk of rutting.

4.9.6 Comparison of Hot Mix and Warm Mix Costs

The total cost for HMA is Rs 8,459.53 per metric ton (excluding the aggregate cost), with most of the cost attributed to the price of bitumen. In contrast, WMA mixtures containing Sasobit and LDPE formulations are associated with elevated costs. The lowest price for WMA is Rs 8,986.77 per MT (at 6% LDPE), and the highest cost is Rs 9,487.04 per MT (at 0% LDPE).

Although the overall costs of WMA formulations are higher than those of HMA, using Sasobit and LDPE has been shown to improve workability and reduce emissions. The cost difference reflects the added value of these benefits.

4.9.7 Effect of Sasobit and LDPE on Costs

Sasobit, priced at Rs 930.00 per kg, significantly increases the cost of WMA. However, it improves the mixture's workability at lower temperatures, making it ideal for use in WMA. LDPE, priced at Rs 10.00 per kg, has a smaller impact on cost but increases proportionally with the quantity added. LDPE enhances the asphalt's flexibility, especially in cooler temperatures.

Although Sasobit and LDPE additives increase the cost of WMA, their contribution to improved performance and workability, particularly in cooler climates, may justify the added expense.

4.9.8 Diesel Savings for Bitumen and Aggregate Heating

Lowering the heating temperatures for both bitumen and aggregate has saved a significant amount of diesel. Reducing the bitumen heating temperature from 150°C to 130°C saved 2,785.31 liters of diesel, which accounts for 13.13% savings in consumption. An equivalent decrease in the aggregate heating value from 180°C to 140°C also showed a 22.02% savings, which translates to 1.35 liters of diesel per MT of asphalt.

These identified savings lead to notable operational savings from a cost evaluation perspective of Rs 113.12 saved per MT from bitumen heating, and from aggregate heating, the saving margin was Rs 436.32 per MT. This demonstrates the need for effective temperature control in reducing the asphalt's production energy costs and decreasing the related emissions, and thus the environmental impact of production.

4.9.9 Financial Impact of Diesel Savings

Economically, reducing the heating temperatures for bitumen and aggregate implemented saves a total of Rs 549.44 per MT of asphalt. This cost reduction enhances the profitability of the entire process of asphalt manufacturing.

Energy cost savings enhance the economic viability of incorporating additives such as Sasobit and LDPE in asphalt production. Additionally, these savings contribute to the sustainability of the process by reducing diesel consumption and associated emissions, thereby making technology more attractive for widespread industrial adoption.

4.9.10 Environmental Impact of LDPE Waste

The use of LDPE waste in the production of WMA provides a green answer to plastic waste management. The asphalt industry can use this LDPE, which would otherwise go to landfills, to tackle plastic pollution and support the circular economy. This method remained sustainable even at higher LDPE contents, up to 6%, where the asphalt mixture maintained its sturdiness and characteristics.

LDPE waste addresses the global plastic pollution crisis and provides an environmentally friendly substitute for conventional asphalt production techniques. This encourages the asphalt industry's environmental ethics and better aligns with rising sustainability targets.

4.9.11 Implications for Sustainability

By incorporating LDPE waste into asphalt mixes, plastic waste is reduced, and the energy consumption and environmental footprint of bitumen production can also be minimized, resulting in cost savings. Repurposing plastic waste in asphalt production helps the industry bolster its image as a responsible sector while supporting sustainability initiatives. Combining reduced diesel consumption with sustainable materials provides a comprehensive solution to "green" asphalt production.

CHAPTER 5. CONCLUSION, RECOMMENDATIONS, AND FUTURE RESEARCH

5.1 Conclusion

This study aimed to investigate and compare the effects of Sasobit and LDPE additives on the performance, cost-effectiveness, and sustainability properties of bituminous mixtures. The results provide critical information on the performance and economics of these materials in asphalt and align closely with previous research regarding the use of LDPE and Sasobit as asphalt additives, while also providing new insights into their combined effects.

The most balanced solution resulted from adding 3% Sasobit and 6% LDPE. This combination keeps all parameters within specific ranges, making it more applicable. The incorporation of Sasobit and LDPE in the asphalt mixtures has shown a significant improvement in their performance. LDPE helped to increase mixture stability, particularly at lower Sasobit levels, due to an increase in the stiffness of the bitumen. However, observed that higher Sasobit levels led to a reduction in stability, which may be due to the softening effects within the mixture's matrix. Variants combining both Sasobit and LDPE also influenced air voids and VMA, showing higher resistance to durability, particularly at acceptable compaction and paving levels. In addition, the increase in LDPE content reduces the bulk density of the mixture due to the lower density of LDPE than bitumen, highlighting the need for compaction. Considering flow values, LDPE increased flexibility, which is beneficial for special purposes, but excessive flexibility may negatively affect stability.

From a cost perspective, while WMA initially appears more expensive than conventional HMA, it offers long-term benefits such as improved workability and substantial energy savings. Sasobit contributed to higher initial costs but enhanced the sustainability of asphalt production by enabling effective compaction at lower temperatures. In contrast, LDPE proved to be cost-effective overall, though its economic advantage diminished at higher concentrations due to reach performance returns.

The environmental and energy benefits of this approach are significant. Lower heating requirements translated into diesel savings and reduced greenhouse gas emissions, with a calculated cost saving of Rs 549.44 per metric ton of asphalt produced. The inclusion of LDPE, a common plastic waste, not only improves certain mechanical properties but also presents a practical solution for sustainable waste management, thereby supporting circular economy objectives.

In conclusion, the combined use of Sasobit and LDPE in asphalt mixtures presents a promising path toward more sustainable, cost-effective, and durable pavement solutions. This dual-modifier strategy addresses key environmental challenges, promotes energy efficiency, and aligns with industry goals for performance and long-term sustainability.

5.2 Recommendations

5.2.1 Optimizing Additive Usage

To balance performance and cost efficiency, maintain LDPE content at moderate levels (e.g., 4-6%). Use Sasobit at concentrations that complement LDPE's effects, avoiding excessive softening of the mixture matrix.

5.2.2 Energy Efficiency Initiatives

Continue exploring methods to lower heating temperatures for bitumen and aggregates, maximizing energy savings without compromising mixture quality. Invest in equipment and technologies that support efficient heating practices.

5.2.3 Plastic Waste Management

Expand the use of LDPE waste in asphalt production to address plastic pollution while improving sustainability. Work with recycling plants to secure a regular flow of LDPE scraps.

5.2.4 Economic Viability

Conduct cost-benefit analysis for extensive WMA formulation application utilizing Sasobit and LDPE. The government must also drive demand for sustainable materials such as asphalt by providing relevant incentives and subsidies.

5.3 Research Limitations and Future Research

5.3.1 Limitations

While the study successfully achieved its main objectives - Assessing the Impact of Waste LDPE and Sasobit Additives on the Performance and Economic Viability of Warm Mix Asphalt in Sri Lanka it is important to acknowledge certain limitations that may influence the generalization of the findings. Firstly, all performance evaluations were carried out under controlled laboratory conditions, which cannot fully replicate the complex and variable nature of field environments. Factors such as varying traffic loads, fluctuating temperatures, moisture infiltration, and long-term aging effects could influence the actual performance of the asphalt in practice. Furthermore, the

study's scope was limited to short-term performance testing; hence, the long-term durability, rutting resistance, and aging characteristics of the modified asphalt mixtures were not comprehensively assessed. These constraints highlight the need for cautious interpretation of the results, particularly when considering large-scale applications in real projects.

5.3.2 Future Research

Building upon the results achieved in this research, future studies should aim to bridge the gap between laboratory findings and field performance. Field trials should be conducted to validate the laboratory results under actual service conditions, considering local load frequencies, traffic patterns, and environmental factors specific to Sri Lanka. Additionally, extended durability studies are necessary to assess how Sasobit and LDPE-modified asphalt mixtures perform over several years, particularly in terms of cracking resistance, moisture susceptibility, and long-term stiffness retention. Exploring the use of alternative waste plastic, such as polypropylene, polyethylene terephthalate (PET), or mixed plastic waste, could also broaden the applicability of this approach and enhance its environmental benefits. Such studies would not only verify the current faith but also provide practical guidance for policymakers, road authorities, and contractors aiming to adopt sustainable asphalt technologies in local infrastructure projects.



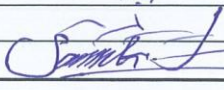
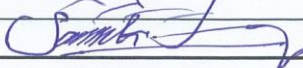
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APPENDIX-A. Laboratory Test Results

	Road Development Authority of Sri Lanka Research & Development Division BITUMEN LABORATORY				
PROPERTIES OF AGGREGATE					
Type of Mix Design : Wearing Course ,Type-1, ICTAD SSCM Table- 506-1, Type of Aggregate : Hot Bin Samples					
Gradings					
Percentage Passing					
Sample no. →					
↓ Sieve Size in mm	HB#1	HB#2	HB#3	HB#4	
28	100	100	100	100	
20	100	100	100	97.6	
10	100	100.0	95.2	1.1	
5	100	65.3	0.4	0.0	
2.36	92.2	3.4	0.0	0.0	
1.18	80.4	0.8	0.0	0.0	
0.600	61.1	0.0	0.0	0.0	
0.300	41.3	0.0	0.0	0.0	
0.150	28.9	0.0	0.0	0.0	
0.075	14.2	0.0	0.0	0.0	
Physical Properties					
Sample no. →					Test Method
↓ TEST	HB#1	HB#2	HB#3	HB#4	
AIV	--	--	23	--	BS:812
LAAV	--	--	39(GrB)		ASTM C131
FI	--	--	26	21	BS:812
SG (DRY)	2.734	2.761	2.781	2.805	ASTM C127-77 & C128-73
SG (APP)	2.789	2.814	2.826	2.831	
Water Abb.	0.81	0.68	0.48	0.39	
			Date	Signature	
Tested by:	W.S.U.S.Wijenayaka	RA	23/09/2025		
Checked by:	S.H.A.S.Kumara	RA	23-09-2025		
Authorized by:	Susantha Langappuli	ME	24-07-2025		



ROAD DEVELOPMENT AUTHORITY

BITUMEN LABORATORY

Research & Development Division
 Borupana Road, Ratmalana, Sri Lanka.
 Tel: 011-2-634701 Fax: 011-2-632649

TESTING OF BITUMEN

Property	Test Method	Unit	Test Results	Specification Limit	
				Min	Max
Penetration 77°F(25°C) 100g, 5s	ASTM D 5/D 5M -13	0.1mm	64	60	70
FlashPoint (Cleveland open cup)	ASTM D 92 -16b	°C	332	232	
Softening Point	ASTM D 36 -D 36M-14	°C	48.0	48	56
Loss on heating for 5 hrs. at 163°C					
1. Loss by weight percent	ASTM D 6 -D 6M-95	%Wt	0.61		1
2. Penetration after Loss on heating test percent of its original value	ASTM D 5/D 5M -13	%	88	75	
Solubility in trichlorethylene	ASTM D 2042 -15	%Wt	99.2	99	
Specific Gravity at 25/25°C	ASTM D 70 -09		1.023	--	--
Kinematic Viscosity at 135 °C	ASTM D 2170/ D 2170 M-10	cSt	356	--	--
Ductility 77°F(25°C) 5cm/min.	ASTM D 113 -99	cm	>100	100	

	Name	Designation	Date	Signature
Tested by:	W.S.U.S.Wijenayaka	Research Assistant	23/07/2025	
Checked by:	S.H.A.S.Kumara	Research Assistant	23-07-2025	
Authorized by:	Susantha Langappuli	Material Engineer	24.07.2025	

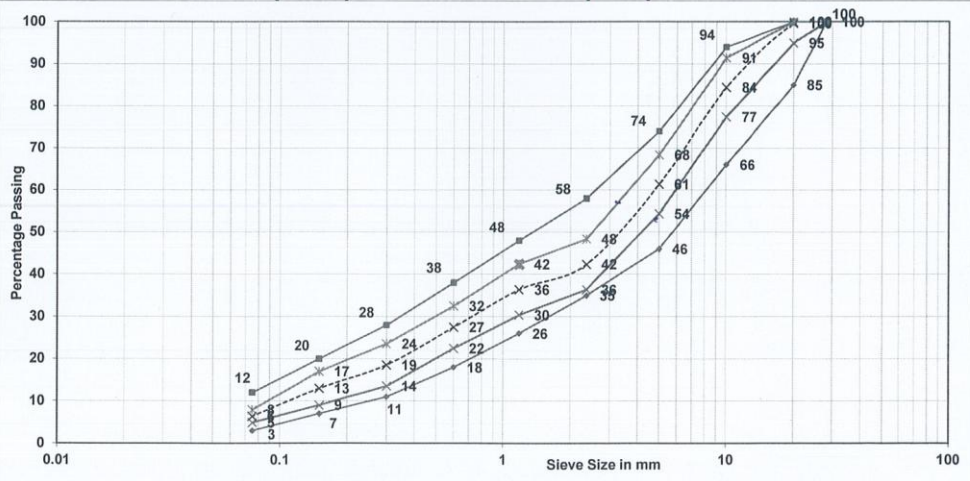


Road Development Authority of Sri Lanka
Research & Development Division
BITUMEN LABORATORY

Blending of Aggregate
Job mix formula & Combined grading

Remarks: Wearing Course-Type-01 ,SSCM Table-506-1 ICTAD

Percentage Passing					Blending Percentage				Sieve Size in mm	Spec Limit		Combined Grading
Sieve Size in mm	HB#1 No :1	HB#2 No :2	HB#3 No :3	HB#4 No :4	No :1 45%	No :2 25%	No :3 15%	No :4 15%		Lower	Upper	
28	100	100	100	100	45.0	25.0	15.0	15.0	28	100	100	100
20	100	100	100	97.6	45.0	25.0	15.0	14.6	20	85	100	100
10	100	100	95.2	1.1	45.0	25.0	14.3	0.2	10	66	94	84
5	100	65.3	0.4	0.0	45.0	16.3	0.1	0.0	5	46	74	61
2.36	92.2	3.4	0.0	0.0	41.5	0.9	0.0	0.0	2.36	35	58	42
1.18	80.4	0.8	0.0	0.0	36.2	0.2	0.0	0.0	1.18	26	48	36
0.600	61.1	0.0	0.0	0.0	27.5	0.0	0.0	0.0	0.600	18	38	27
0.300	41.3	0.0	0.0	0.0	18.6	0.0	0.0	0.0	0.300	11	28	19
0.150	28.9	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.150	7	20	13
0.075	14.2	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.075	3	12	6



	Name	Designation	Date	Signature
Tested by:	W.S.U.S. Wijenayaka	RA	23/02/2025	
Checked by:	S.H.A.S.Kumara	RA	23-02-2025	
Authorized by:	Susantha Langappuli	ME	24-02-2025	



**Road Development Authority
Research & Development Division
Central Laboratory - Ratmalana**

PROJECT: -----

LOCATION: -----

DATE: -----

DESCRIPTION OF SAMPLES : Hot bin samples

MIX PROPORTION :

FRACTION SIZE, (MM)

PERCENTAGE PASSING

Specific Gravity (DRY)

Specific Gravity (Apparent)

HB#1	HB#2	HB#3	HB#4
45	25	15	15
2.734	2.761	2.781	2.805
2.789	2.814	2.826	2.831

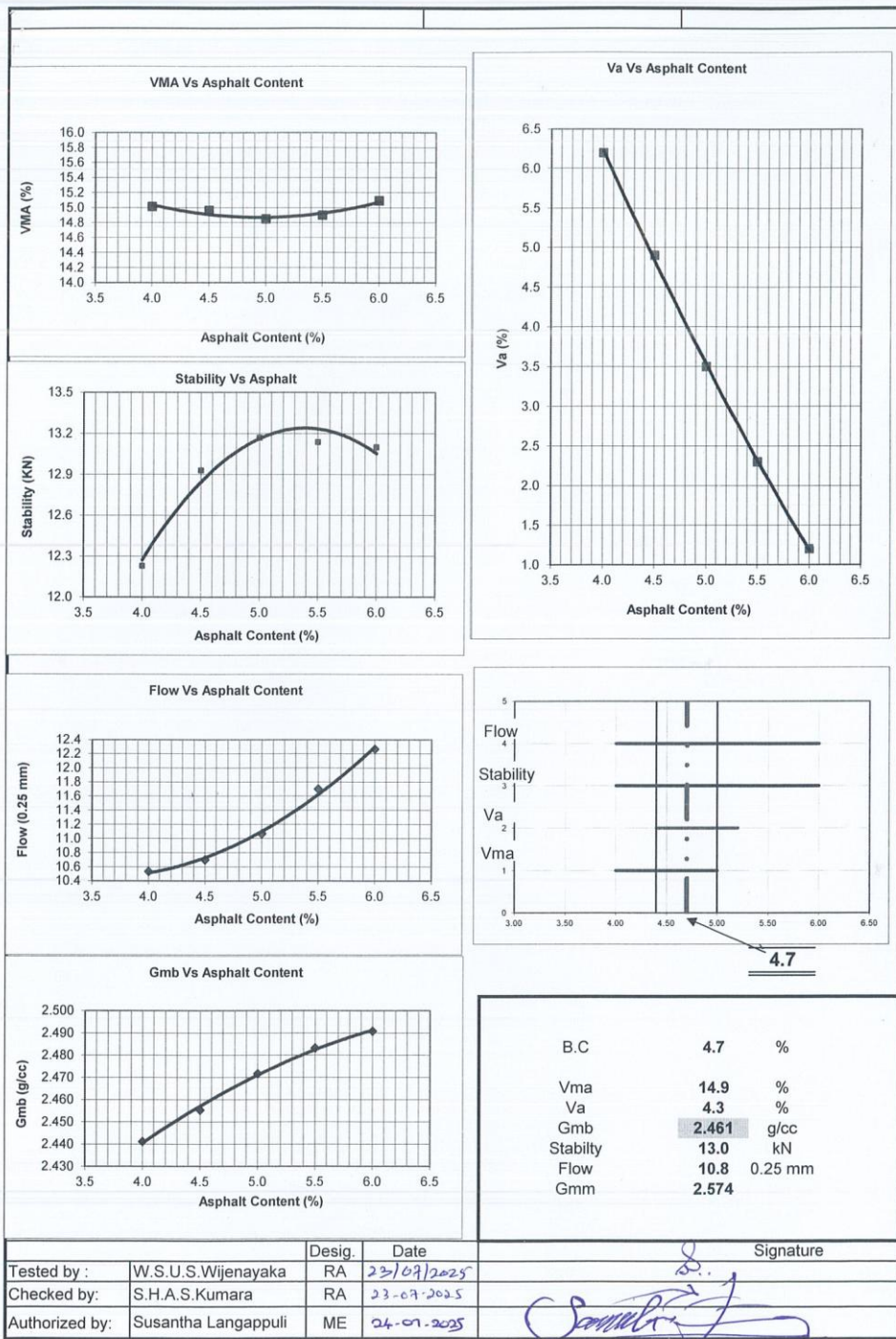
* SPECIFIC GRAVITY OF ASPHALT (G_b) : 1.023
 * BULK SPEC.GRAVITY OF MIXED AGG.(G_{sb}) : 2.758
 * APP. SPEC.GRAVITY OF MIXED AGG.(G_{sa}) : 2.807
 * EFFE. SPEC.GRAVITY OF MIXED AGG.(G_{se}) : 2.783
 * ABSORBED ASPHALT % BY WT. OF MIX (P_{ba}): 0.333
 * PENETRATION GRADE OF ASPHALT 60/70

*Compaction temperature is to be established as such the kinematic viscosity in 280 +/- 30 cSt

*Mixing temperature is to be established as such the kinematic viscosity in 170 +/- 20 cSt

Specimen No.	Asphalt % by total wt. Of mix % (P _b)	Effective asphalt cont by total Wt. Of mix % (P _b e)	Weight (gms)			Bulk Volume (V _{mb})	Specific gravity of compacted mix		Effec. Asphalt cont. by wt. of mix (V _b e)	Air voids volume as % of V _{mb} (V _a)	Inter granular voids space volume as % (V _{ma})	Voids filled with asphalt % (V _{FB})	Unit Weight g/cc	Stability			Flow (0.25mm)
			In Air	In Water	In Air & Water		Bulk (G _{mb}) g/cc	Maximum (G _{mm}) g/cc						Measured		Final (kN)	
														Load (kN)	Correla-tion ratio		
1	4.0	3.7	1248.0	740.8	1252.3	511.5	2.440					2.440	12.4	1.00	12.4	9.8	
2	4.0	3.7	1242.3	737.8	1246.8	509.0	2.441					2.441	12.2	1.00	12.2	10.6	
3	4.0	3.7	1236.2	733.3	1239.3	506.0	2.443					2.443	12.1	1.00	12.1	11.2	
						0.0	2.441	2.603	8.8	6.2	15.0	58.5			12.2	10.5	
4	4.5	4.2	1241.4	740.3	1245.7	505.4	2.456					2.456	12.8	1.04	13.3	10.6	
5	4.5	4.2	1238.7	737.6	1242.0	504.4	2.456					2.456	12.1	1.04	12.6	11.4	
6	4.5	4.2	1237.2	736.1	1240.2	504.1	2.454					2.454	12.4	1.04	12.9	10.1	
						0.0	2.455	2.583	10.0	4.9	15.0	67.1			12.9	10.7	
7	5.0	4.7	1242.8	742.9	1245.6	502.7	2.472					2.472	12.2	1.04	12.7	10.6	
8	5.0	4.7	1241.6	741.5	1243.7	502.2	2.472					2.472	12.7	1.04	13.2	11.8	
9	5.0	4.7	1239.2	740.0	1241.6	501.6	2.470					2.470	13.1	1.04	13.6	10.8	
						0.0	2.472	2.562	11.3	3.5	14.8	76.2			13.2	11.1	
10	5.5	5.2	1231.8	736.1	1232.5	496.4	2.481					2.481	12.8	1.04	13.3	11.2	
11	5.5	5.2	1238.3	741.4	1239.7	498.3	2.485					2.485	12.4	1.04	12.9	11.8	
12	5.5	5.2	1235.5	739.3	1236.8	497.5	2.483					2.483	12.7	1.04	13.2	12.1	
						0.0	2.483	2.542	12.6	2.3	14.9	84.5			13.1	11.7	
13	6.0	5.7	1225.5	734.6	1226.1	491.5	2.493					2.493	12.2	1.04	12.7	10.8	
14	6.0	5.7	1235.3	740.5	1236.7	496.2	2.490					2.490	12.9	1.04	13.4	12.3	
15	6.0	5.7	1237.1	741.3	1238.2	496.9	2.490					2.490	12.7	1.04	13.2	13.7	
						0.0	2.491	2.522	13.8	1.2	15.1	91.7			13.1	12.3	

	Name	Designation	Date	Signature
Tested by:	W.S.U.S.Wijenayaka	RA	23/07/2025	
Checked by:	S.H.A.S.Kumara	RA	23-07-2025	
Authorized by:	Susantha Langappuli	ME	24.07.2025	



	Desig.	Date
Tested by :	W.S.U.S.Wijenayaka	RA 23/09/2025
Checked by :	S.H.A.S.Kumara	RA 23-09-2025
Authorized by :	Susantha Langappuli	ME 24-09-2025

Signature



ROAD DEVELOPMENT AUTHORITY

BITUMEN LABORATORY

Research & Development Division
 Borupana Road, Ratmalana, Sri Lanka.
 Tel: 011-2-634701 Fax: 011-2-632649

TESTING OF BITUMEN

3% Sasobit

Property	Test Method	Unit	Test Results	Specification Limit	
				Min	Max
Penetration 77°F(25°C) 100g, 5s	ASTM D 5/D 5M -13	0.1mm	32		
FlashPoint (Cleveland open cup)	ASTM D 92 -16b	°C			
Softening Point	ASTM D 36 -D 36M-14	°C	78.0		
Loss on heating for 5 hrs. at 163°C					
1. Loss by weight percent	ASTM D 6 -D 6M-95	%Wt			
2. Penetration after Loss on heating test percent of its original value	ASTM D 5/D 5M -13	%			
Solubility in trichlorethylene	ASTM D 2042 -15	%Wt			
Specific Gravity at 25/25°C	ASTM D 70 -09				
Kinematic Viscosity at 135 °C	ASTM D 2170/ D 2170 M-10	cSt			
Ductility 77°F(25°C) 5cm/min.	ASTM D 113 -99	cm	106		

	Name	Designation	Date	Signature
Tested by:	W.S.U.S.Wijenayaka	Research Assistant	23/07/2025	
Checked by:	S.H.A.S.Kumara	Research Assistant	23-07-2025	
Authorized by:	Susantha Langappuli	Material Engineer	24-07-2025	



ROAD DEVELOPMENT AUTHORITY

BITUMEN LABORATORY
 Research & Development Division
 Borupana Road, Ratmalana, Sri Lanka.
 Tel: 011-2-634701 Fax: 011-2-632649

TESTING OF BITUMEN

5% Sasobit

Property	Test Method	Unit	Test Results	Specification Limit	
				Min	Max
Penetration 77°F(25°C) 100g, 5s	ASTM D 5/D 5M -13	0.1mm	29		
FlashPoint (Cleveland open cup)	ASTM D 92 -16b	°C			
Softening Point	ASTM D 36 -D 36M-14	°C	84.0		
Loss on heating for 5 hrs. at 163°C					
1. Loss by weight percent	ASTM D 6 -D 6M-95	%Wt			
2. Penetration after Loss on heating test percent of its original value	ASTM D 5/D 5M -13	%			
Solubility in trichlorethylene	ASTM D 2042 -15	%Wt			
Specific Gravity at 25/25°C	ASTM D 70 -09				
Kinematic Viscosity at 135 °C	ASTM D 2170/ D 2170 M-10	cSt			
Ductility 77°F(25°C) 5cm/min.	ASTM D 113 -99	cm	97		

	Name	Designation	Date	Signature
Tested by:	W.S.U.S.Wijenayaka	Research Assistant	23/07/2025	
Checked by:	S.H.A.S.Kumara	Research Assistant	23-07-2025	
Authorized by:	Susantha Langappuli	Material Engineer	24-07-2025	



**ROAD DEVELOPMENT AUTHORITY OF SRI LANKA
RESEARCH & DEVELOPMENT DIVISION
CENTRAL LABORATORY - RATMALANA
MARSHALL MIX DESIGN**

PROJECT : 3% Sasobit + 2% LDPE
LOCATION:
DATE :
DESCRIPTION OF SAMPLES : Hot Bin Samples for Asphalt Concrete Wearing Course.
MIX PROPORTION :
FRACTION SIZE, (MM)
PERCENTAGE PASSING
Specific Gravity (DRY)
Specific Gravity (Apparent)

	HB#1	HB#2	HB#3	HB#4
FRACTION SIZE, (MM)	45	25	15	15
PERCENTAGE PASSING				
Specific Gravity (DRY)	2.734	2.761	2.781	2.805
Specific Gravity (Apparent)	2.789	2.814	2.826	2.831

* SPECIFIC GRAVITY OF ASPHALT (Gb) : 1.023
 * BULK SPEC.GRAVITY OF MIXED AGG. (Gsb) : 2.758
 * APP. SPEC.GRAVITY OF MIXED AGG. (Gsa) : 2.807
 * EFFE. SPEC.GRAVITY OF MIXED AGG. (Gse) : 2.783
 * ABSORBED ASPHALT % BY WT. OF MIX (Pba): 0.304
 * PENETRATION GRADE OF ASPHALT : 60/70

Specimen No.	Comp. Temp.	Asphalt % by total wt. Of mix % (Pb)	Effective asphalt cont. by total Wt. Of mix % (Pbe)	Weight (gms)			Bulk Volume (Vmb)	Specific gravity of compacted mix		Effec. Asphalt cont. by wt. of mix (Vbe)	Air voids volume as % of Vmb (Va)	Inter granular voids space volume as % (Vma)	Voids filled with asphalt % (VFB)	Unit Weight g/cc	Stability				
				In Air	In Water	S.S.D. In Air		Bulk (Gmb) g/cc	Maximum (Gmm) g/cc						Measured		Correlation ratio	Final (KN)	Flow (0.25mm)
															Dial reading (Div)	Load (KN)			
1		4.7	4.4103	1255.2	747.2	1256.9	509.7	2.463					2.463		9.2	1.00	9.2	10.8	
2		4.7	4.4103	1256.4	747.3	1257.4	510.1	2.463					2.463		9.8	1.00	9.8	11.6	
3		4.7	4.4103	1248.3	743.2	1249.8	506.6	2.464					2.464		9.7	1.04	10.1	11.7	
							0	2.463	2.574	10.6	4.3	14.9	71.08					9.7	11.4

Tested by : *W.S.U.S. Wijenayake*
23/07/2025

Checked by : *S.H.A.S. Kumara*
23-07-2025

Susantha Langappuli
SUSANTHA LANGAPPULI
MATERIAL ENGINEER
 R & D Division
 R. D. A.
 RATMALANA, T. P. 263470*
 Material Engineer : *Susantha Langappuli*
24-07-2025



**ROAD DEVELOPMENT AUTHORITY OF SRI LANKA
RESEARCH & DEVELOPMENT DIVISION
CENTRAL LABORATORY - RATMALANA
MARSHALL MIX DESIGN**

PROJECT : 3% Sasobit + 4% LDPE
 LOCATION :
 DATE :
 DESCRIPTION OF SAMPLES : Hot Bin Samples for Asphalt Concrete Wearing Course.
 MIX PROPORTION :
 FRACTION SIZE, (MM) :
 PERCENTAGE PASSING :
 Specific Gravity (DRY) :
 Specific Gravity (Apparent) :

* SPECIFIC GRAVITY OF ASPHALT (Gb) : 1.023
 * BULK SPEC.GRAVITY OF MIXED AGG.(Gsb) : 2.758
 * APP. SPEC.GRAVITY OF MIXED AGG.(Gsa) : 2.807
 * EFFE. SPEC.GRAVITY OF MIXED AGG.(Gse) : 2.783
 * ABSORBED ASPHALT % BY WT. OF MIX (Pba) : 0.304
 * PENETRATION GRADE OF ASPHALT : 60/70

	HB#1	HB#2	HB#3	HB#4
FRACTION SIZE, (MM)	45	25	15	15
PERCENTAGE PASSING	2.734	2.761	2.781	2.805
Specific Gravity (DRY)	2.789	2.814	2.826	2.831
Specific Gravity (Apparent)				

Specimen No.	Comp. Temp.	Asphalt % by total wt. Of mix % (Pb)	Effective asphalt cont. by total Wt. Of mix % (Pbe)	Weight (gms)			Bulk Volume (Vmb)	Specific gravity of compacted mix		Effec. Asphalt cont. by wt. of mix (Vbe)	Air voids volume as % of Vmb (Va)	Inter granular voids space volume as % (Vma)	Voids filled with asphalt % (VFB)	Unit Weight g/cc	Stability			Flow (0.25mm)	
				In Air	In Water	S.D. in Air		Bulk (Gmb) g/cc	Maximum (Gmm) g/cc						Measured		Correlation ratio		Final (KN)
															Dial reading (Div)	Load (KN)			
1		4.7	4.4103	1254.2	744.2	1255.3	511.1	2.454					2.454		10.7	1.00	10.7	10.4	
2		4.7	4.4103	1256.2	744.3	1257.8	513.5	2.446					2.446		9.9	1.00	9.9	11.6	
3		4.7	4.4103	1246.8	740.2	1247.9	507.7	2.456					2.456		10.8	1.00	10.8	10.3	
							0	2.452	2.574	10.6	4.8	15.3	68.97					10.5	10.8

Tested by : *W.S.U.S. Wijenayake*

Checked by : *S.H.A.S. Kumara*

SUSANTHA LANGAPPULI
MATERIAL ENGINEER
 R & D Division
 R. D. A.
 RATMALANA, T. P 263470

Susantha Langappuli

23/08/2025

23-08-2025

24-07-2025



**ROAD DEVELOPMENT AUTHORITY OF SRI LANKA
RESEARCH & DEVELOPMENT DIVISION
CENTRAL LABORATORY - RATMALANA
MARSHALL MIX DESIGN**

PROJECT : 3% Sasobit + 6% LDPE
LOCATION:
DATE :
DESCRIPTION OF SAMPLES : Hot Bin Samples for Asphalt Concrete Wearing Course.
MIX PROPORTION :
FRACTION SIZE, (MM)
PERCENTAGE PASSING
Specific Gravity (DRY)
Specific Gravity (Apparent)

HB#1	HB#2	HB#3	HB#4
45	25	15	15
2.734	2.761	2.781	2.805
2.789	2.814	2.826	2.831

* SPECIFIC GRAVITY OF ASPHALT (Gb) : 1.023
 * BULK SPEC.GRAVITY OF MIXED AGG. (Gsb) : 2.758
 * APP. SPEC.GRAVITY OF MIXED AGG. (Gsa) : 2.807
 * EFFE. SPEC.GRAVITY OF MIXED AGG. (Gse) : 2.783
 * ABSORBED ASPHALT % BY WT. OF MIX (Pba): 0.304
 * PENETRATION GRADE OF ASPHALT : 60/70

Specimen No.	Comp. Temp.	Asphalt % by total wt. Of mix % (Pb)	Effective asphalt cont. by total Wt. Of mix % (Pbe)	Weight (gms)			Bulk Volume (Vmb)	Specific gravity of compacted mix		Effec. Asphalt cont. by wt. of mix (Vbe)	Air voids volume as % of Vmb (Va)	Inter granular voids space volume as % (Vma)	Voids filled with asphalt % (VFB)	Unit Weight g/cc	Stability				
				In Air	In Water	S.S. In Air		Bulk (Gmb) g/cc	Maximum (Gmm) g/cc						Measured		Correlation ratio	Final (KN)	Flow (0.25mm)
															Dial reading (Div)	Load (KN)			
1		4.7	4.4103	1245.3	740.2	1246.8	506.6	2.458					2.458		11.4	1.00	11.4	11.6	
2		4.7	4.4103	1249.9	740.3	1250.9	510.6	2.448					2.448		10.9	1.00	10.9	10.8	
3		4.7	4.4103	1251.1	740.2	1252.4	512.2	2.443					2.443		11.6	1.00	11.6	11.4	
							0	2.450	2.574	10.6	4.9	15.4	68.52					11.3	11.3

Tested by : *S.*
 W.S.U.S.Wijenayake
 23/09/2025

Checked by : *S.H.A.S.Kumara*
 S.H.A.S.Kumara
 23-09-2025

Material Engineer : *Susantha Langappuli*
 SUSANTHA LANGAPPULI
 MATERIAL ENGINEER
 R & D Division
 R. D. A.
 RATMALANA, T. P. 263470
 24.07.2025



ROAD DEVELOPMENT AUTHORITY OF SRI LANKA
RESEARCH & DEVELOPMENT DIVISION
CENTRAL LABORATORY - RATMALANA
MARSHALL MIX DESIGN

PROJECT : 3% Sasobit + 8% LDPE
LOCATION:
DATE :
DESCRIPTION OF SAMPLES Hot Bin Samples for Asphalt Concrete Wearing Course.
MIX PROPORTION :
FRACTION SIZE, (MM)
PERCENTAGE PASSING
Specific Gravity (DRY)
Specific Gravity (Apparent)

* SPECIFIC GRAVITY OF ASPHALT (Gb) : 1.023
 * BULK SPEC.GRAVITY OF MIXED AGG. (Gsb) : 2.758
 * APP. SPEC.GRAVITY OF MIXED AGG. (Gsa) : 2.807
 * EFFE. SPEC.GRAVITY OF MIXED AGG. (Gse) : 2.783
 * ABSORBED ASPHALT % BY WT. OF MIX (Pba) : 0.304
 * PENETRATION GRADE OF ASPHALT : 60/70

HB#1	HB#2	HB#3	HB#4
45	25	15	15
2.734	2.761	2.781	2.805
2.789	2.814	2.826	2.831

Specimen No.	Comp. Temp.	Asphalt % by total wt. Of mix % (Pb)	Effective asphalt cont by total Wt. Of mix % (Pbe)	Weight (gms)			Bulk Volume (Vmb)	Specific gravity of compacted mix		Effec. Asphalt cont. by wt. of mix (Vbe)	Air voids volume as % of Vmb (Va)	Inter granular voids space volume as % (Vma)	Voids filled with asphalt % (VFB)	Unit Weight g/cc	Stability				
				In Air	In Water	In Air S C S		Bulk (Gmb) g/cc	Maximum (Gmm) g/cc						Measured		Correlation ratio	Final (KN)	Flow (0.25mm)
															Dial reading (Div)	Load (KN)			
1	4.7	4.4103	1246.2	737.6	1247.8	510.2	2.443						2.443	11.6	1.00	11.6	11.6		
2	4.7	4.4103	1251.3	740.8	1252.9	512.1	2.443						2.443	11.9	1.00	11.9	11.8		
3	4.7	4.4103	1247.6	737.4	1248.9	511.5	2.439						2.439	11.6	1.00	11.6	11.9		
						0	2.442	2.574	10.5	5.2	15.7	67.12					11.7	11.8	

Tested by : W.S.U.S.Wijenayake
 23/07/2025

Checked by : S.H.A.S.Kumara
 23-07-2025

SUSANTHA LANGAPPULI
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 Material Engineer : Susantha Langappuli
 24-07-2025



ROAD DEVELOPMENT AUTHORITY OF SRI LANKA
RESEARCH & DEVELOPMENT DIVISION
CENTRAL LABORATORY - RATMALANA
MARSHALL MIX DESIGN

PROJECT : 5% Sasobit + 2% LDPE
LOCATION:
DATE :
DESCRIPTION OF SAMPLES : Hot Bin Samples for Asphalt Concrete Wearing Course.
MIX PROPORTION :
FRACTION SIZE (MM)
PERCENTAGE PASSING
Specific Gravity (DRY)
Specific Gravity (Apparent)

* SPECIFIC GRAVITY OF ASPHALT (Gb) : 1.023
 * BULK SPEC.GRAVITY OF MIXED AGG. (Gsb) : 2.758
 * APP. SPEC.GRAVITY OF MIXED AGG. (Gsa) : 2.807
 * EFFE. SPEC.GRAVITY OF MIXED AGG. (Gse) : 2.783
 * ABSORBED ASPHALT % BY WT. OF MIX (Pba) : 0.304
 * PENETRATION GRADE OF ASPHALT : 60/70

	HB#1	HB#2	HB#3	HB#4
FRACTION SIZE (MM)	45	25	15	15
PERCENTAGE PASSING	2.734	2.761	2.781	2.805
Specific Gravity (DRY)	2.789	2.814	2.826	2.831
Specific Gravity (Apparent)	2.789	2.814	2.826	2.831

Specimen No.	Comp. Temp.	Asphalt % by total wt. Of mix % (Pb)	Effective asphalt cont. by total Wt. Of mix % (Pbe)	Weight (gms)			Bulk Volume (Vmb)	Specific gravity of compacted mix		Effec. Asphalt cont. by wt. of mix (Vbe)	Air voids volume as % of Vmb (Va)	Inter granular voids space volume as % (Vma)	Voids filled with asphalt % (VFB)	Unit Weight g/cc	Stability				
				In Air	In Water	S.S.D. in Air		Bulk (Gmb) g/cc	Maximum (Gmm) g/cc						Measured		Correlation ratio	Final (KN)	Flow (0.25mm)
															Dial reading (Div)	Load (KN)			
1		4.7	4.4103	1244.2	737.2	1247.8	510.6	2.437					2.437		8.2	1.00	8.2	11.3	
2		4.7	4.4103	1243.6	736.3	1246.8	510.5	2.436					2.436		7.9	1.00	7.9	12.4	
3		4.7	4.4103	1245.6	737.2	1249.2	512.0	2.433					2.433		8.4	1.00	8.4	11.8	
							0	2.435	2.574	10.5	5.4	15.9	65.99					8.2	11.8


Tested by : 
 W.S.U.S. Wijenayake

23/07/2025

Checked by : 
 S.H.A.S. Kumara

23-07-2025

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
**ROAD DEVELOPMENT AUTHORITY OF SRI LANKA
RESEARCH & DEVELOPMENT DIVISION
CENTRAL LABORATORY - RATMALANA
MARSHALL MIX DESIGN**

PROJECT : 5% Sasobit + 4% LDPE
LOCATION:
DATE :
DESCRIPTION OF SAMPLES : Hot Bin Samples for Asphalt Concrete Wearing Course.
MIX PROPORTION :
FRACTION SIZE, (MM)
PERCENTAGE PASSING


	HB#1	HB#2	HB#3	HB#4
	45	25	15	15
Specific Gravity (DRY)	2.734	2.761	2.781	2.805
Specific Gravity (Apparent)	2.789	2.814	2.826	2.831

* SPECIFIC GRAVITY OF ASPHALT (Gb) : 1.023
 * BULK SPEC.GRAVITY OF MIXED AGG. (Gsb) : 2.758
 * APP. SPEC.GRAVITY OF MIXED AGG. (Gsa) : 2.807
 * EFFE. SPEC.GRAVITY OF MIXED AGG. (Gse) : 2.783
 * ABSORBED ASPHALT % BY WT. OF MIX (Pba) : 0.304
 * PENETRATION GRADE OF ASPHALT : 60/70

Specimen No.	Comp. Temp.	Asphalt % by total wt. Of mix % (Pb)	Effective asphalt cont. by total Wt. Of mix % (Pbe)	Weight (gms)			Bulk Volume (Vmb)	Specific gravity of compacted mix		Efec. Asphalt cont. by wt. of mix (Vbe)	Air voids volume as % of Vmb (Va)	Inter granular voids space volume as % (Vma)	Voids filled with asphalt % (VFB)	Unit Weight g/cc	Stability				
				In Air	In Water	S.S.D. IN AIR		Bulk (Gmb) g/cc	Maximum (Gmm) g/cc						Measured		Correlation ratio	Final (KN)	Flow (0.25mm)
															Dial reading (Div)	Load (KN)			
1		4.7	4.4103	1248.3	736.3	1251.3	515.0	2.424					2.424	9.2	1.00	9.2	12.4		
2		4.7	4.4103	1246.7	735.8	1249.6	513.8	2.426					2.426	7.9	1.00	7.9	12.6		
3		4.7	4.4103	1245.3	736.1	1248.9	512.8	2.428					2.428	8.6	1.00	8.6	12.3		
							0	2.426	2.574	10.5	5.8	16.2	64.50				8.6	12.4	

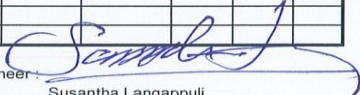
Tested by : 
 W.S.U.S. Wijenayake

23/07/2025

Checked by : 
 S.H.A.S. Kumara

23-07-2025

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24-07-2025



ROAD DEVELOPMENT AUTHORITY OF SRI LANKA
RESEARCH & DEVELOPMENT DIVISION
CENTRAL LABORATORY - RATMALANA
MARSHALL MIX DESIGN

PROJECT : 5% Sasobit + 8% LDPE
LOCATION:
DATE :
DESCRIPTION OF SAMPLES : Hot Bin Samples for Asphalt Concrete Wearing Course.
MIX PROPORTION :
FRACTION SIZE, (MM)
PERCENTAGE PASSING

HB#1	HB#2	HB#3	HB#4
45	25	15	15
2.734	2.761	2.781	2.805
2.789	2.814	2.826	2.831

Specific Gravity (DRY)
Specific Gravity (Apparent)

* SPECIFIC GRAVITY OF ASPHALT (Gb) : 1.023
 * BULK SPEC.GRAVITY OF MIXED AGG. (Gsb) : 2.758
 * APP. SPEC.GRAVITY OF MIXED AGG. (Gsa) : 2.807
 * EFFE. SPEC.GRAVITY OF MIXED AGG. (Gse) : 2.783
 * ABSORBED ASPHALT % BY WT. OF MIX (Pba) : 0.304
 * PENETRATION GRADE OF ASPHALT : 60/70

Specimen No.	Comp. Temp.	Asphalt % by total wt. Of mix % (Pb)	Effective asphalt cont. by total Wt. Of mix % (Pbe)	Weight (gms)			Bulk Volume (Vmb)	Specific gravity of compacted mix		Effec. Asphalt cont. by wt of mix (Vbe)	Air voids volume as % of Vmb (Va)	Inter granular voids space volume as % (Vma)	Voids filled with asphalt % (VFB)	Unit Weight g/cc	Stability				
				In Air	In Water	S.S. in Air		Bulk (Gmb) g/cc	Maximum (Gmm) g/cc						Measured		Correlation ratio	Final (KN)	Flow (0.25mm)
															Dial reading (Div)	Load (KN)			
1		4.7	4.4103	1251.4	734.4	1254.6	520.2	2.406					2.406	8.4	1.00	8.4	11.9		
2		4.7	4.4103	1253.9	733.1	1255.2	522.1	2.402					2.402	8.5	1.00	8.5	12.1		
3		4.7	4.4103	1254.8	732.2	1253.4	521.2	2.408					2.408	8.3	1.00	8.3	12.2		
							0	2.405	2.574	10.4	6.6	17.0	61.15				8.4	12.1	

Tested by : W.S.U.S. Wijenayake

23/07/2025

Checked by : S.H.A.S. Kumara

23-07-2025

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Material Engineer : Susantha Langappuli

24-07-2025

APPENDIX-B. Diesel Consumption Data – Keragala Asphalt Plant



KERAGALA ASPHALT PLANT ROAD DEVELOPMENT AUTHORITY

- ❖ Data Collection Period: June 2023 – October 2023
- ❖ Purpose: To analyse diesel consumption patterns in asphalt production and bitumen / aggregate heating processes.

- During the period from June to October 2023, asphalt production (Wearing Course) and diesel consumption for aggregate heating are presented in Table 1 below. In this process, the aggregate was typically heated to 180 °C.

Table 1

Month	Total Production (MT)	Diesel Consumption (Liters)
June	2,103.60	11,052.08
July	694.79	3,541.15
August	1,677.68	7,789.69
September	1,280.15	9,412.53
October	1,883.49	15,005.21
Total	7,639.71	46,800.66

- During the period from June to October 2023, asphalt production (Cutback) and diesel consumption for aggregate heating are presented in Table 2 below. In this process, the aggregate was typically heated to 140 °C.

Table 2

Month	Total Production (MT)	Diesel Consumption (Liters)
June	53.77	214.78
July	59.29	236.45
August	34.62	163.96
September	133.07	641.49
October	88.86	510.00
Total	369.61	1,766.68

- During the period from June to October 2023, the total asphalt production (Wearing Course + Cutback) and the total diesel consumption for aggregate heating are presented in Table 3 below.



Table 3

Total Production (MT)	8,009.32
Total Diesel Consumption for Aggregate heating (liters)	48,567.34

- During the period from June to October 2023, diesel consumption for heating bitumen to 130°C and subsequently to 150°C is presented in Table 4. Each day, the initial diesel reading was taken once the bitumen reached 130°C, and then heating continued up to 150°C, after which the total diesel consumption was recorded.

Table 4

Month	Production (MT)	Diesel Consumption (Liters)	
		Upto 150° C	Upto 130° C
June	2,157.37	6,432.14	5,735.24
July	754.08	2,989.40	2,571.27
August	1,712.30	4,338.35	3,566.17
September	1,413.22	3,449.98	2,992.63
October	1,972.35	4,001.79	3,561.04
Total	8,009.32	21,211.66	18,426.35

Role	Name & Designation	Signature
Prepared By	M.S.N. Kumara	
Checked By	A.A. Adikari, Senior Research Assistant	
Certified By	D.M.P. Medagama, Mechanical Engineer	