PERFORMANCE OF PERVIOUS ASPHALT PAVEMENT USING WASTE POLYETHYLENE MODIFIED BINDER



By

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A thesis submitted in partial fulfilment of the requirements for the degree of

MASTER of SCIENCE in Civil Engineering

Department of Civil Engineering

CHITTAGONG UNIVERSITY OF ENGINEERING & TECHNOLOGY

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Declaration

I hereby declare that the work contained in this Thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the Thesis contains no material previously published or written by another person except where due reference is cited. Furthermore, the Thesis complies with PLAGIARISM and ACADEMIC INTEGRITY regulation of CUET.

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Dedication

I dedicate this thesis to my family members.

Approval/Declaration by the Supervisor

This is to certify that Shovon Halder, Student ID: 15MCE010P, has carried out this research work under my supervision, and that he has fulfilled the relevant Academic Ordinance of the Chittagong University of Engineering & Technology, so that he is qualified to submit the following Thesis in the application for the degree of MASTER of SCIENCE in Civil Engineering. Furthermore, the Thesis complies with the PLAGIARISM and ACADEMIC INTEGRITY regulations of CUET.

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(Author)

Abstract

The escalating demand for sustainable and resilient pavement solutions, coupled with growing environmental concerns regarding polyethylene waste, has catalyzed the exploration of innovative materials within pavement engineering. This study undertook an experimental evaluation of pervious asphalt pavement utilizing waste polyethylene-modified bitumen to enhance mechanical strength and functional durability, while promoting sustainable waste repurposing. In Bangladesh, where the rainy season lasts nearly seven to eight months, conventional pavements face persistent drainage challenges and reduced lifespan.

In this study, 60/70 penetration grade bitumen was modified by incorporating 3%, 4%, 5%, and 6% waste polyethylene by weight. Binder tests—including penetration, softening point, ductility, viscosity, temperature susceptibility, and others—revealed that 4% polyethylene addition produced the most favorable results. The modified binder exhibited enhanced stiffness and lower susceptibility to temperature changes, with penetration values ranging from 11 at 5°C to 49 at 35°C, compared to 6 to 152 for unmodified bitumen. The optimum binder content (OBC) was determined to be within the range of 5.25–5.4%, based on Cantabro abrasion and draindown test results. The mix satisfied the Cantabro loss threshold of 15% and the maximum allowable draindown limit of 0.3%, as per MS-2. The air void content was also verified to be within the range of 18–22%, ensuring adequate permeability.

Performance tests showed that polyethylene-modified mixes outperformed conventional mixes. Dry Marshall stability increased from 1.86 kN to 4.70 kN, and retained stability improved from 71.5% for the neat binder to 90.4% for the

modified mix, exceeding the minimum requirement of 75%. The Tensile Strength Ratio (TSR) also improved from 85% to 97%, indicating higher resistance to moisture damage. The coefficient of permeability increased from 3 mm/s in conventional mixes to 4.2 mm/s in modified mixes, confirming improved infiltration potential.

These findings confirm that incorporating waste polyethylene enhances the structural and functional performance of pervious asphalt pavement, while also addressing environmental waste concerns. The proposed mix shows promise for low-volume roads and parking lots, particularly in high-rainfall regions, and offers a basis for future field applications and study.

বিমূর্ত

নির্মাণ খাতে পরিবেশবান্ধব ও টেকসই রাস্তা তৈরির চাহিদা দিন দিন বাড়ছে। পাশাপাশি, পলিথিন বর্জ্য নিয়ে পরিবেশগত উদ্বেগও ক্রমেই তীব্র হচ্ছে। এই প্রেক্ষাপটে, রাস্তা নির্মাণে নতুন ও কার্যকর উপকরণ ব্যবহারের চেষ্টা জোরদার হয়েছে। এই গবেষণায় বর্জ্য পলিথিন দিয়ে সংশোধিত বিটুমিন ব্যবহার করে পানিপারগম্য অ্যাসফাল্ট রাস্তার কার্যকারিতা পরীক্ষামূলকভাবে মূল্যায়ন করা হয়েছে। গবেষণার মূল উদ্দেশ্য ছিল পানিপারগম্য অ্যাসফাল্টের যান্ত্রিক শক্তি ও স্থায়িত্ব বৃদ্ধি করা এবং একইসঙ্গে পরিবেশের জন্য ক্ষতিকর পলিথিন বর্জ্যকে পুনর্ব্যবহারের মাধ্যমে টেকসই সমাধান নিশ্চিত করা। বাংলাদেশের জলবায়ু, বিশেষ করে সাত থেকে আট মাস দীর্ঘ বর্ষাকাল, যেখানে সড়কে পানি জমে দীর্ঘস্থায়ী সমস্যা তৈরি করে—এ বিষয়টি গবেষণাকে আরও প্রাসঙ্গিক করে তুলেছে।

গবেষণায় ৬০/৭০ গ্রেডের বিটুমিনে বিভিন্ন মাত্রায় বর্জ্য পলিথিন মিশিয়ে সংশোধিত বিটুমিনের ভৌত বৈশিষ্ট্য পরীক্ষা করা হয়। পেনিট্রেশন, সফটেনিং পয়েন্ট, ডাকটিলিটি, সান্দ্রতা ও তাপমাত্রা সংবেদনশীলতার মতো পরীক্ষাগুলোতে দেখা গেছে, ৪% পলিথিন সংযোজন সবচেয়ে ভালো ফলাফল দিয়েছে। এই পরিমাণে পলিথিন সংযোজনে বিটুমিনের শক্তি ও তাপমাত্রা সহনশীলতা বৃদ্ধি পেয়েছে। যেমন, সংশোধিত বিটুমিনের পেনিট্রেশন মান ৫ ডিগ্রি সেলসিয়াসে ১১ এবং ৩৫ ডিগ্রি সেলসিয়াসে ৪৯ পাওয়া গেছে, যেখানে প্রচলিত বিটুমিনের মান ছিল ৬ থেকে ১৫২—যা তাপমাত্রার তারতম্যের প্রতি বেশি সংবেদনশীল। পরবর্তী ধাপে, এই সংশোধিত বিটুমিন ব্যবহার করে পানিপারগম্য অ্যাসফাল্ট মিশ্রণ প্রস্তুত করা হয়। ক্যান্টাব্রো অ্যাব্রেশন ও ড্রেইনডাউন পরীক্ষার মাধ্যমে সর্বোত্তম বাইন্ডার পরিমাণ নির্ধারণ করা হয় ৫.২৫% থেকে ৫.৪% এর মধ্যে। প্রচলিত নির্দেশিকা অনুযায়ী, মিশ্রণের ড্রেইনডাউন সর্বোচ্চ সীমা ০.৩% এর মধ্যে ছিল এবং ঘর্ষণজনিত ক্ষয় ১৫% এর সীমার মধ্যেই ছিল। পাশাপাশি, মিশ্রণের ভেতর বাতাসের পরিমাণ ১৮–২২% এর মধ্যে থাকায় পর্যাপ্ত পানি নিঃসরণের নিশ্চয়তা পাওয়া গেছে।

পারফরম্যান্স টেস্টের ফলাফল অনুযায়ী, বর্জ্য পলিথিন সংশোধিত মিশ্রণ প্রচলিত মিশ্রণের তুলনায় অধিক কার্যকর প্রমাণিত হয়েছে। ড্রাই মার্শাল স্ট্যাবিলিটি ১.৮৬ কিলোনিউটন থেকে বেড়ে ৪.৭ কিলোনিউটনে উন্নীত হয়েছে এবং রিটেইনড স্ট্যাবিলিটি নিট বিটুমিনের ক্ষেত্রে ৭১.৫% থেকে সংশোধিত মিশ্রণে ৯০.৪% হয়েছে, যা ৭৫% এর ন্যূনতম মানদণ্ড অতিক্রম করে। প্রসারণ শক্তি অনুপাত ৮৫% থেকে ৯৭% হয়েছে, যা আর্দ্রতা-জনিত ক্ষয় প্রতিরোধে উন্নত সক্ষমতা নির্দেশ করে। এছাড়াও, পরিবর্তিত মিশ্রণের পারমিয়াবিলিটি ৩ মিমি/সেকেন্ড থেকে বেড়ে ৪.২ মিমি/সেকেন্ড হয়েছে, যা পানি নিষ্কাশনে আরও কার্যকরতা নির্দেশ করে।

সার্বিকভাবে, এই গবেষণার ফলাফল প্রমাণ করে যে বর্জ্য পলিথিন দিয়ে সংশোধিত বিটুমিন ব্যবহার করলে রাস্তার স্থায়িত্ব ও কার্যকারিতা উভয়ই বাড়ে। একইসঙ্গে এটি পরিবেশবান্ধব বর্জ্য ব্যবস্থাপনার একটি কার্যকর দিক নির্দেশ করে। প্রস্তাবিত এই মিশ্রণটি শহরে কম যানবাহন চলাচলযুক্ত সড়ক ও পার্কিং এরিয়া নির্মাণে বিশেষভাবে উপযোগী, বিশেষ করে যেসব এলাকায় অতিবর্ষণ ঘটে। এই গবেষণাটি মাঠপর্যায়ের প্রয়োগের জন্য ভিত্তি তৈরি করেছে এবং ভবিষ্যতে এ ধরনের প্রযুক্তি আরও বিস্তারে উৎসাহিত করবে।

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Nomenclature

AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BS	British Standard
CRMB	Crumb Rubber Modified Bitumen
EPDM	Ethylene Propylene Diene Monomer
EVA	Ethylene Vinyl Acetate
HDPE	High-Density Polyethylene
HMA	Hot Mix Asphalt
IDT	Indirect Tensile Test
ITS	Indirect Tensile Strength
IRC	Indian Roads Congress
LAAV	Los Angeles Abrasion Value
LDPE	Low-Density Polyethylene
MQ	Marshall Quotient
MS-2	Manual Series 2 (Asphalt Mix Design Methods)
NCHRP	National Cooperative Highway Research Program
OBC	Optimum Binder Content
PE	Polyethylene
PET	Polyethylene Terephthalate
PMB	Polymer Modified Bitumen
PP	Polypropylene
PVC	Polyvinyl Chloride
RHD	Roads and Highways Department (Bangladesh)
SBS	Styrene-Butadiene-Styrene
SBR	Styrene-Butadiene Rubber
TFO	Thin Film Oven
TSR	Tensile Strength Ratio

Chapter 1: INTRODUCTION

1.1 GENERAL

Transportation networks are fundamental to the socio-economic development of any country, serving as the backbone for mobility and economic activities. As a crucial component of these networks, pavements promote the effective flow of people and products, enhancing economic development and living standards. With improvements in pavement technology, the transportation infrastructure has changed dramatically on a global scale, improving environmental performance, sustainability, and longevity. Conventional asphalt pavements are commonly utilized because they are inexpensive and easy to install. Nevertheless, rutting, cracking, and environmental deterioration are potential issues with these pavements. To address these challenges, many countries have adopted substitute pavement choices. Recently, there has been an increasing focus on sustainable pavement technologies. This includes the use of recycled and reclaimed materials and innovative alternatives like pervious pavements. Pervious pavements, also known as porous pavements, are a promising technique for managing rainwater, mitigating the urban heat island effect, and reducing noise levels without sacrificing structural integrity. Pervious asphalt pavement (PAP) has become increasingly popular in urban centers at risk of flooding and in initiatives focused on enhancing stormwater management (Boogaard et al., 2014).

The implementation of these new pavement technologies in advanced nations has been primarily driven by the need to address issues such as increased traffic congestion, the impact of climate change, and rapid urban development. For instance, countries like the United States, Japan, and several European

nations have conducted thorough research and implemented advanced pavement systems, including pervious pavements. The concept of pervious pavements originated in the mid-20th century, initially designed to combat urban flooding and improve water quality in densely populated areas (Boogaard et al., 2014).

In contrast, Bangladesh, a developing nation with a rapidly growing economy, faces unique challenges in its transportation sector. The country's pavement infrastructure is often subjected to severe weather conditions, heavy traffic, and insufficient maintenance, leading to premature deterioration and high repair costs. While widely used, traditional asphalt pavements are not always suitable for the harsh conditions prevalent in Bangladesh. Consequently, there is a pressing need to explore alternative pavement technologies offering enhanced performance and sustainability. According to research, adding waste polyethylene to asphalt binder can enhance the pavement's mechanical qualities, such as its flexibility, durability, and resistance to deformation under heavy loads (Zoorob and Suparma, 2000). These enhancements are especially advantageous in areas like Bangladesh, where pavements are subjected to harsh environmental and traffic conditions. Furthermore, the use of recycled materials in pavement construction coincides with global sustainability goals and encourages circular economy practices, diverting plastic waste from landfills and seas (Huang et al., 2009).

The sustainability of these systems is further improved by incorporating waste materials into construction techniques. One such waste product that has drawn interest is polyethylene (PE), which can enhance the performance qualities of asphalt binders. Due to its non-biodegradable nature and large volume in municipal solid waste streams, waste polyethylene (PE), which is typically

derived from discarded plastic bags, bottles, and packaging materials, poses a serious environmental threat. Waste polyethylene is used in asphalt binders to improve the asphalt's mechanical qualities while offering a way to recycle this persistent contaminant. The lifetime of the pavement, its resistance to deformation, and its resilience have all improved with modified binders.

Bangladesh, akin to numerous other nations, is facing the difficulty of managing plastic garbage. A staggering 3000 tons of plastic and polyethylene waste are produced daily in Bangladesh (Shaibur et al., 2024). In the city of Chattogram, approximately 250 tons of plastic-polyethylene waste are disposed of (Pial and Al-Amin, 2022). Although there are sixty-four districts in Bangladesh, the majority of the production comes from Dhaka, Chattogram, and Narayanganj, which are important commercial hubs in Bangladesh (Islam, 2012). The percentage of polyethylene-plastic industries is depicted in Fig. 1.1. So, the problems associated with plastic and polyethylene waste are acute in these regions. Plastic trash produced in the nation is made of polyethylene, commonly used in bottles, plastic bags, and packaging materials. When polyethylene waste is not properly disposed of, it puts marine life at risk and causes serious environmental problems like soil and water contamination. To manage the mounting waste problem and lessen the environmental impact, polyethylene trash must be recycled into valuable resources.

The use of waste polyethylene-modified binders in pervious asphalt pavements offers a comprehensive answer to Bangladesh's dual challenges of waste management and sustainable infrastructure development. This novel solution not only solves the serious issue of polyethylene waste by redirecting it away from landfills, but it also improves the longevity and effectiveness of pervious pavement. PAP's high void content necessitates the use of a binder with

improved performance properties, which can be accomplished by using waste polyethylene.

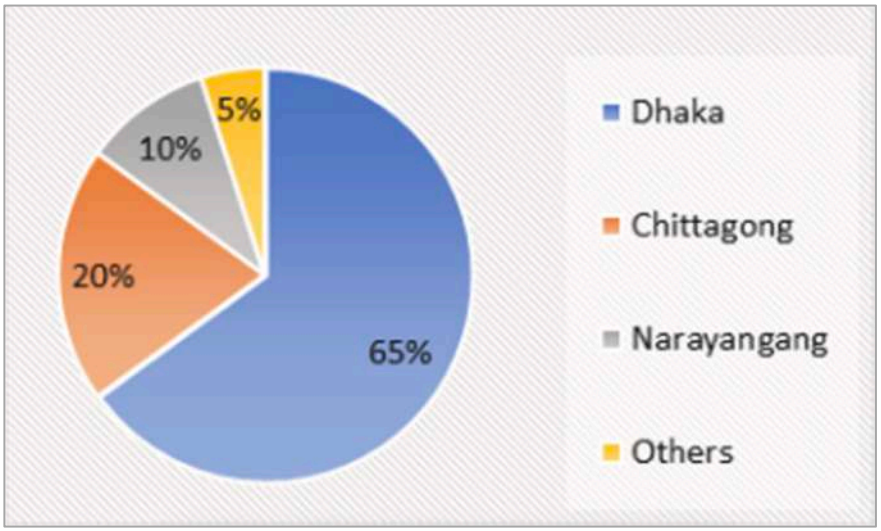


Fig. 1.1: Polyethylene-Plastic industries in Bangladesh (Islam, 2012)

One of the standout benefits of pervious pavement is how much it can improve surface drainage. Unlike traditional pavements that don't let water through and worsen stormwater runoff, pervious pavements allow rainwater to seep through them. This helps prevent standing water, better manage urban flooding, and lessen the pressure on stormwater systems. Plus, they help recharge groundwater, making them a great choice for sustainable water management. Using pervious pavement in our cities can boost environmental resilience and improve the overall efficiency of our infrastructure.

In conclusion, the investigation of pervious asphalt pavement employing waste polyethylene-modified binder represents a significant development in pavement engineering. It provides a long-term solution for pavement design, addressing both environmental and performance issues. Given these factors, the Department of Civil Engineering at Chittagong University of Engineering & Technology (CUET), an initiative has been taken to investigate the potential

usability of waste polyethylene modified pervious asphalt pavement, focusing on its performance improvement. This research has the potential to change pavement construction techniques in Bangladesh and elsewhere, enabling the creation of resilient, long-lasting, and environmental-friendly transportation infrastructure.

1.2 NEED FOR THE PRESENT STUDY

Bangladesh is facing significant environmental challenges as well as increased demand for its infrastructure. Traditional asphalt pavements, while widely used, frequently experience durability concerns due to the country's harsh weather, excessive traffic, and inadequate upkeep. This causes frequent repairs, increased expenses, and transportation interruptions. There is an urgent need for alternate pavement materials and technologies that provide improved performance and sustainability. Using pervious asphalt pavements modified by waste polyethylene is one possible solution. Pervious pavements have the potential to successfully manage stormwater by minimizing surface runoff, increasing groundwater recharge, and mitigating urban flooding. These benefits are especially important in Bangladesh, where excessive rains and inadequate drainage systems frequently result in waterlogging and flooding. However, the usage of pervious pavements in Bangladesh has been restricted because of concerns about mechanical strength and long-term durability.

This is where the waste polyethylene comes in. Polyethylene, a form of plastic, is infamously difficult to dispose of because it does not degrade readily, resulting in considerable environmental damage and filling landfills. By adding waste polyethylene into the asphalt binder, we can not only make good use of this problematic waste but also improve the mechanical properties of the pavement. According to numerous studies, polyethylene-modified asphalt

binders can improve pavement flexibility, deformation resistance, and overall durability, making them better suited to the harsh circumstances in Bangladesh. Furthermore, using waste polyethylene in pavement construction contributes to global sustainability goals and promotes the circular economy. Reusing polyethylene-plastic waste reduces landfill loads and environmental pollution while also creating more durable infrastructure. This innovative recycling strategy may act as a blueprint for other developing nations encountering comparable issues.

Despite these potential benefits, there has been no systematic investigation into the performance of pervious asphalt pavements made with waste polyethylene-modified binders, particularly in Bangladesh. This knowledge gap underscores the importance of this study, which will assess the feasibility, performance, and environmental impact of such pavements. It is expected that this research will generate valuable insights that can lead to the practical application and wider adoption of this revolutionary technology in Bangladesh as well as abroad.

1.3 PROBLEM STATEMENT

In contemporary civil engineering, creating and maintaining long-lasting, environmentally friendly pavement systems presents formidable obstacles. Despite being widely utilized, traditional asphalt pavements frequently experience degradation from moisture-induced distresses (Fig. 1.2). These issues are more noticeable in areas with heavy traffic and harsh weather, necessitating expensive and regular maintenance. In addition, the environmental consequences associated with conventional pavement materials and building techniques have spurred the hunt for more environmentally friendly substitutes.



Fig. 1.2: Damage to roads in Chattogram in the monsoon period ("Rainfall leaves Chittagong city roads battered," 2015)



Fig. 1.3: Comparison of conventional asphalt (left) to porous asphalt (right) during a rainstorm ("Office of Water Resources Permit Application Portal | Rhode Island Department of Environmental Management," n.d.)

Conventional asphalt pavements frequently overlook important stormwater management concerns in favour of durability and load-bearing capacity. These pavements' impermeable qualities cause significant surface runoff, which exacerbates urban flooding, waterlogging, and water body

contamination. Climate change exacerbates these problems by making extreme weather events more frequent and intense, which puts additional demand on the pavement infrastructure already in place. Furthermore, harsh weather and high traffic levels weaken the structural integrity of conventional asphalt pavements, requiring expensive and regular maintenance procedures.

Novel pavement systems that can efficiently manage stormwater while preserving structural integrity under high traffic loads are desperately needed. By permitting water to percolate through its surface, pervious asphalt pavement (PAP) provides a possible solution by lowering runoff, replenishing groundwater, and lowering the danger of flooding. Furthermore, by strengthening skid resistance, PAP can help lower the urban heat island effect and increase road safety. The performance of pervious pavement compared to conventional pavement in terms of stormwater management is illustrated in Fig. 1.3. However, the high void content required for its permeability may compromise PAP's durability and load-bearing capacity, especially in situations with high traffic and harsh environmental stresses.

Simultaneously, there has been a growing need worldwide to manage plastic trash, particularly polyethylene. Because it is not biodegradable, polyethylene, which is widely used in bottles, bags, and packaging, makes up a large amount of plastic trash and poses serious environmental risks. Polyethylene waste should be disposed of properly to prevent pollution of the environment, obstruction of drainage systems, and harm to both marine and terrestrial ecosystems. Innovative recycling solutions are required because the volume and persistence of polyethylene-plastic garbage have proven to be too much for current waste management tactics to handle. The problems associated with waste disposal are shown in Fig. 1.4.



(a)



(b)

Fig. 1.4: Plastic and polyethylene waste disposal problems (a) Clogging of the Chaktai Khal, Chattogram ("Plastic pollution choking Ctg canals," 2024) , and **(b) A huge landfill of plastic-polyethylene waste** ("Plastic-polythene waste major source of waterlogging in Chittagong," n.d.)

Enhancing the mechanical qualities of the pavement and offering a sustainable method for managing polyethylene waste are two key benefits of incorporating waste polyethylene into asphalt binders. Improves in elasticity,

resistance to deformation, and general durability have been shown for polyethylene-modified binders (PEMB). These improvements are essential for ensuring that pervious asphalt pavements can endure high traffic volumes and environmental pressures without losing their permeability. They also help the pavements function as intended. Moreover, the inclusion of waste polyethylene contributes to better thermal stability of the binder, reducing susceptibility to temperature-induced cracking and rutting. This enhances the long-term performance of the pavement under varying climatic conditions.

Despite the promising potential of combining pervious asphalt pavement with polyethylene-modified binders, several critical questions remain unanswered:

1. **Performance and Durability**: How does the incorporation of waste polyethylene affect the long-term performance and durability of pervious asphalt pavements under various climatic and traffic conditions?
2. **Structural Integrity**: Can pervious asphalt pavements with polyethylene-modified binders maintain their structural integrity and load-bearing capacity without compromising permeability?
3. **Drainage Performance:** How much does using waste polyethylene-modified binders affect how well pervious asphalt pavements drain, especially in places that experience heavy rainfall and often have water pooling on the surface?
4. **Environmental Impact**: What are the environmental effects of incorporating waste polyethylene into asphalt binders, particularly regarding possible emissions during production and the comprehensive lifecycle analysis?

5. **Economic Feasibility**: Is the integration of waste polyethylene into asphalt binders economically feasible for large-scale implementation?

A thorough analysis, including fieldwork, laboratory testing, and in-depth environmental impact assessments, is necessary to answer these concerns. Field trials will give data on the actual performance of the modified binders, while laboratory tests will evaluate their mechanical qualities. Assessments of the environmental impact will guarantee that the suggested fixes are in line with sustainability objectives. The aim of this study is to close current knowledge gaps and offer evidence-based perspectives on the viability and efficiency of pervious asphalt pavements amended with waste polyethylene. Through a thorough investigation of these facets, the study aims to support the creation of environmentally friendly pavement solutions that improve traffic efficiency and advance environmental sustainability through efficient waste management.

1.4 OBJECTIVES OF THE STUDY

This investigation aims to predict the performance of waste polyethylene-modified binders used in pervious asphalt pavement in terms of binder and mixture properties. This prediction will be based on the evaluation of laboratory tests. Based on the problem stated above, the specific objectives are as follows:

1. Laboratory evaluation of neat and modified binder characteristics to select the suitable concentration of waste PE in the neat binder.
2. Determination of the optimal modified binder content for the preparation of bituminous mixes.
3. Water sensitivity analysis of neat and modified bituminous mixes to assess the water sensitiveness of modified binder.

4. To observe the effectiveness of water infiltration rate through bituminous mixes prepared by waste polyethylene modified binder and conventional binder as well.

1.5 SCOPE OF THE STUDY

This study covers a comprehensive evaluation of the performance and feasibility of using waste polyethylene-modified binders in pervious asphalt pavements, with a specific focus on the context of Bangladesh. The research begins with a laboratory analysis aimed at determining the optimal waste polyethylene content through meticulous material characterization. This involves assessing the mechanical properties and performance characteristics of both neat and modified binders to identify the most suitable concentration of polyethylene to enhance binder performance.

Following the determination of the optimal polyethylene content, the study employs the National Cooperative Highway Research Program (NCHRP) method to ascertain the optimum binder content. This method ensures that the modified binder meets the required standards for durability and functionality in pavement applications. After establishing the optimum binder content, water sensitivity tests are conducted to evaluate the moisture susceptibility of the polyethylene-modified binder. These tests compare the performance of the modified binder against neat bitumen, focusing on its ability to resist moisture-induced damage, which is crucial for maintaining pavement integrity in regions with heavy rainfall.

Finally, the study measures the infiltration rate of the pervious asphalt pavement constructed with the optimized polyethylene-modified binder. This step is essential to verify the pavement's permeability and its effectiveness in

managing stormwater. By assessing the infiltration rate, the research aims to confirm that the modified binder not only enhances the mechanical properties and durability of the pavement but also maintains the essential permeability characteristics of pervious asphalt.

Overall, this study provides a thorough investigation into the use of waste polyethylene in pervious asphalt pavements, addressing key aspects such as material characterization, binder optimization, moisture susceptibility, and permeability. The findings are expected to contribute significantly to developing sustainable and effective pavement solutions for secondary roads, parking lots, and other low-traffic areas in Bangladesh, thereby enhancing infrastructure resilience and environmental sustainability.

1.6 ORGANIZATION OF THE THESIS

In this study, the research work carried out is divided into different topics and presented in five chapters.

The first chapter presents a brief introduction to the problem statement, with special emphasis on the objectives of the proposed study.

Chapter 2 offers a detailed examination of the current literature on pervious asphalt pavements and the use of waste polyethylene as a modifier for asphalt binders. The research explores existing studies, findings, and technological advancements in the field, highlighting the gaps that this study aims to address. This review presents the theoretical framework and contextual background essential for the investigation.

Chapter 3 primarily focuses on examining the materials and methods utilized in the study. It provides a comprehensive overview of the characteristics and preparation techniques for waste polyethylene and asphalt binder, as well as detailing the methodology used in the experiments. In this chapter, the methodologies for creating mixtures and evaluating their performance, as well as the laboratory techniques utilized to analyze the characteristics of unaltered and adjusted binding agents, are discussed.

Chapter 4 discusses the results of the laboratory tests and performance reviews. The optimum amount of waste polyethylene to add to the binder, the mixes' sensitivity to water, and the modified binder's general efficacy for building pervious asphalt pavement are all covered.

Chapter 5 outlines the research's main conclusions, along with their implications for pavement design and construction. It makes suggestions for further investigation and useful applications, outlining ways in which the findings of this study can be applied to enhance pavement sustainability and performance.

Chapter 2: LITERATURE REVIEW

2.1 GENERAL

This chapter contains descriptions of different types of pavements and pervious pavement, various types of polymers, blending mechanisms, common sources of polymers, and their applications both domestically and internationally. The primary purpose of the literature review is to provide a comprehensive analysis of the existing research and advancements in pervious asphalt pavements, particularly emphasizing the incorporation of waste polyethylene (PE) as a modifier for binders. This section of the scholarly work integrates current knowledge, highlights areas requiring further investigation, and lays the groundwork for the current study. The inclusion of waste polyethylene (PE) into asphalt binders presents a potentially effective strategy for enhancing pavement durability and sustainability, thus addressing the environmental challenges associated with polyethylene waste. The review begins with a summary of previous research on asphalt pavements, discussing their properties and performance. The study will first explore the methods and advantages of using waste polyethylene for binder modification. Subsequently, the research will examine the water resistance of the modified binders. Finally, this study evaluates the effectiveness of incorporating polyethylene-treated binders in the context of pervious asphalt applications, drawing on relevant research findings and case studies to support this assessment.

2.2 COMMONLY USED PAVEMENT

Pavements are essential elements of our infrastructure, providing safe and durable surfaces for transportation. They are classified into different types based

on design, materials, and construction methods, with each type suited for specific environmental and traffic conditions. The two main categories of pavement are flexible pavement and rigid pavement. These types differ in their structural features, performance characteristics, and maintenance needs.

2.2.1 Flexible Pavement

Flexible pavements represent the predominant form of road construction globally. In Bangladesh, these pavements make up about 95% of all paved roads. They are built in layers, with a bituminous surface layer resting on top of the base, subbase, and subgrade layers. This layered system allows the stress from traffic loads to be distributed progressively to the lower layers. Asphalt concrete (AC) is the main material used for the surface layer, offering excellent flexibility and the ability to adapt to different traffic conditions. A typical cross-section of flexible pavement with its different layers is shown in Fig. 2.1.

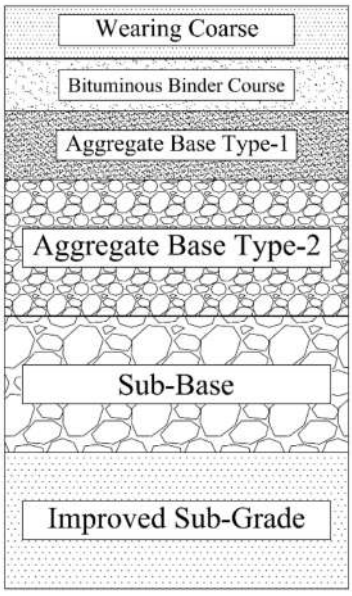


Fig. 2.1: Typical Cross-sectional profile of flexible pavement (Hamim et al., 2021)

A notable advantage of flexible pavements is their capacity to endure minor settlements of the subgrade without incurring significant cracking. This characteristic renders them appropriate for regions with diverse soil conditions, such as Bangladesh, where soft, clayey soils are prevalent. However, it's essential to keep in mind that these pavements need regular maintenance due to issues like rutting, fatigue cracking, and the oxidation of bitumen that can occur over time. To ensure they remain in good condition and continue to perform well under heavy traffic, implementing effective maintenance strategies such as resurfacing and sealing any cracks that arise is crucial.

2.2.2 Rigid Pavement

Rigid pavements, predominantly composed of Portland cement concrete (PCC), are characterized by their exceptional strength and durability. In contrast to flexible pavements, rigid pavements effectively distribute loads over a broader area due to the inherent high stiffness of the concrete slabs. The thickness of the slabs and the spacing of joints primarily determine the load-carrying capacity of rigid pavements, rather than the support from the underlying layers. Rigid pavements are frequently utilized in high-traffic highways, airport runways, and industrial zones, where the demands for heavy loads and an extended service life are paramount. A representative cross-section of rigid pavement, illustrating all its layers, is depicted in Fig. 2.2.

Rigid pavements, composed primarily of concrete, represent a relatively minor segment of the overall road network within the country. Although the initial construction costs for rigid pavements are estimated to be 10 to 15 percent higher than those of flexible pavements, they provide a significantly extended design lifespan of 20 to 25 years. Furthermore, the maintenance costs associated with rigid pavements are considerably lower. Consequently, the total life cycle

cost for rigid pavements is approximately 50 percent less than that of their flexible counterparts. Given these long-term advantages, there is an increasing inclination toward the implementation of rigid pavement solutions in Bangladesh aimed at improving the durability and sustainability of road infrastructure.

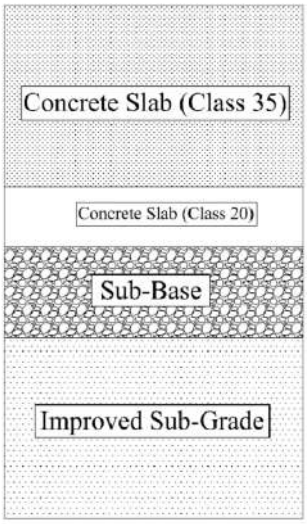


Fig. 2.2: Typical Cross-sectional profile of rigid pavement (Hamim et al., 2021)

2.2.3 Characteristics of Conventional Pavement

Conventional pavements, predominantly categorized into flexible pavements and rigid pavements, represent traditional forms of road infrastructure engineered to withstand traffic loads and environmental factors. Each pavement system consists of multiple layers, each serving an essential function in guaranteeing the pavement's serviceability and longevity. Regarding flexible pavements, the structure typically consists of a surface course, a binder course, a base course, a sub-base course, and subgrade. The surface course, composed of bituminous mixtures, functions as the primary layer to resist traffic wear and provide a smooth riding surface. Located beneath this layer, the binder course efficiently distributes traffic loads to the base course, which is typically

made up of crushed stone or aggregate material. The sub-base layer offers additional structural support and facilitates drainage, while the subgrade, composed of prepared natural soil, serves as the foundation for the entire pavement system. Flexible pavements are engineered to flex under traffic loads and accommodate minor adjustments due to slight subgrade movements. The load transfer mechanism of flexible pavements through its different layers, mentioned earlier, is illustrated in Fig. 2.3.

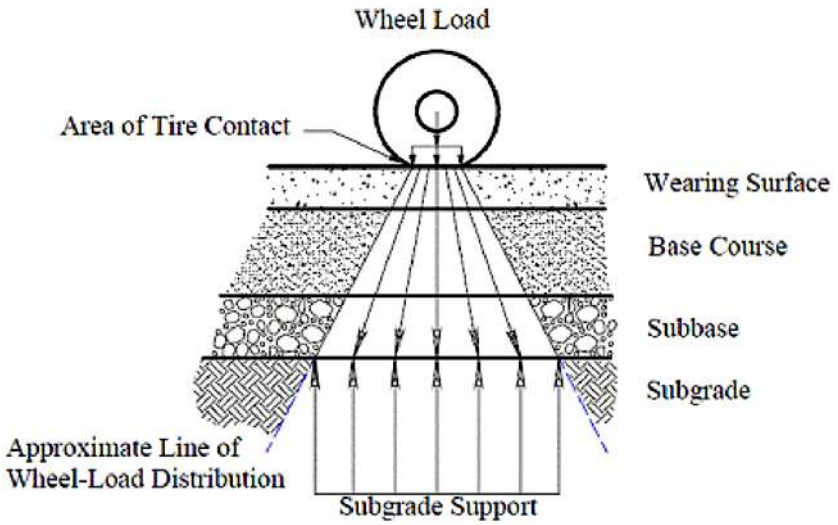


Fig. 2.3: Distribution of load stresses through different layers of flexible pavement (Singh and Mittal, 2018)

Conversely, rigid pavements are mainly composed of a high-strength concrete slab, typically using Portland cement concrete (PCC), which is placed directly on a base course or occasionally a lean concrete base. This concrete slab functions as the primary load-bearing layer, effectively distributing vehicle loads across a wide area owing to its excellent flexural strength. A sub-base layer is often incorporated to provide additional support and minimize moisture-related damage, but it is not mandatory. Load distribution mechanism in rigid pavement is shown in Fig. 2.4. Rigid pavements exhibit less susceptibility to deformation and boast better load distribution properties than flexible pavements. Nonetheless, they necessitate joints to accommodate shrinkage and thermal

stresses, since cracking may arise from temperature changes and subgrade settlement.

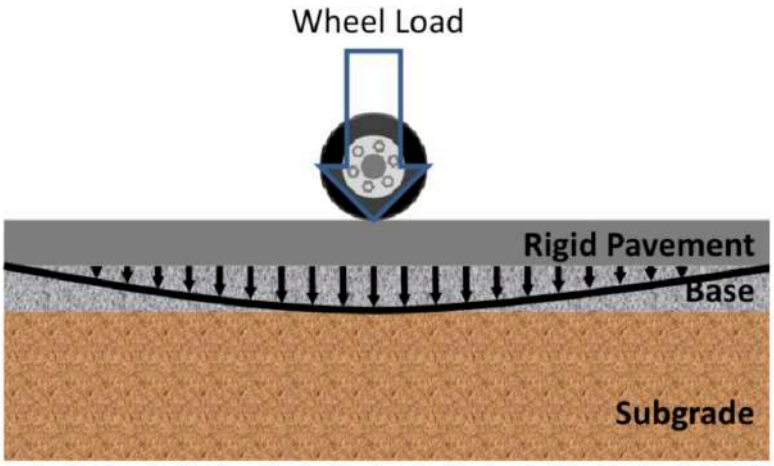


Fig. 2.4: Load Distribution in Rigid Pavement (Rao et al., 2021)

The materials commonly used for flexible pavements include bitumen, aggregates (both coarse and fine), and sometimes additives to improve mix properties (Huang, 2008). Rigid pavements primarily consist of cement, fine and coarse aggregates, and water, sometimes with admixtures included to enhance workability and durability. The construction of both flexible and rigid pavements carries environmental impacts. The production of bitumen generates considerable greenhouse gas emissions, while the extraction and processing of aggregates lead to habitat destruction and resource depletion (Mladenovič et al., 2015). In the context of rigid pavements, the process of cement manufacturing is characterized by significant energy consumption, resulting in the release of considerable quantities of carbon dioxide (CO_2) into the atmosphere (Scrivener et al., 2018). Additionally, both types of pavements often result in increased surface runoff due to their impermeable characteristics, which can disrupt local water cycles and contribute to urban flooding. Construction often involves significant use of natural resources along with emissions of particulate matter and pollutants from machinery. This highlights the importance of adopting

sustainable construction methods and recycling materials in contemporary pavement engineering (Zaumanis, 2014).

2.3 PERVIOUS PAVEMENT

Pervious pavement is a specialized pavement type engineered to permit water infiltration through its surface, diminishing surface runoff and promoting groundwater recharge. Pervious pavement can be both flexible pavement and rigid pavement. This sustainable pavement system is receiving increasing global acknowledgment for its effectiveness in managing urban stormwater, mitigating flood risks, and preventing environmental degradation. Pervious pavements are commonly implemented in parking lots, pedestrian pathways, and low-traffic roadways where water runoff management is essential. The subsequent subsections will explore the characteristics, performance, types, applications, and benefits of pervious pavement.

2.3.1 Characteristics and Performance

Permeable pavements are composed of three primary layers: a porous surface layer, an underlying base layer that provides structural support and enhances storage capacity, and a subgrade layer that facilitates infiltration into the underlying soil. The void content within the surface layer, which typically ranges from 15% to 25%, is crucial for preserving permeability while also ensuring adequate strength to support vehicular traffic loads (Ferguson, 2005). In contrast to conventional pavements that produce impervious surfaces, pervious pavements promote natural infiltration, enabling rainwater to penetrate the ground rather than gathering on the surface.

The performance of pervious pavement is greatly influenced by the choice of materials and the design specifications in place. This type of pavement is made up of a permeable surface layer, an aggregate base designed for water storage, and a subgrade layer that promotes infiltration. To improve the strength and durability of pervious pavements, polymer-modified binders and supplementary materials, like waste polyethylene, can be utilized (Giustozzi, 2016). Although pervious pavements may demonstrate a marginally reduced load-bearing capacity in comparison to conventional asphalt or concrete roadways, they are appropriate for regions experiencing moderate traffic loads. They are effective in mitigating hydroplaning, skidding, and the accumulation of surface water.

2.3.2 Types and Applications

The pervious pavement concept is a relatively novel approach to constructing low-traffic roadways, driveways, sidewalks, parking areas, etc. It is gaining the attention of engineers for its advantages over the impervious pavement. Permeable or pervious pavement has several hydrological advantages. Pervious pavement helps to reduce the peak discharge of runoff to the stormwater drainage system. It also helps to reduce the pollutant concentration from the stormwater by trapping the biological pollutants, hence improving the water quality of the streams and lakes (Selbig and Buer, 2018). The pervious pavement also increases the skid resistance of the surface layer and visibility of the marker on the road, and reduces the heat island problem (Haselbach et al., 2006). There are two main types of pervious pavement commonly utilized: (i) pervious concrete (PC) pavement and (ii) pervious asphalt (PA) pavement. While other varieties of pervious pavement exist, these two are the most prevalent.

i) Pervious Concrete Pavement: This pavement type consists of a mixture of cement, coarse aggregate, and water, with minimal or no fine aggregate. This mixture creates a very porous structure, allowing for efficient water drainage. Pervious concrete is often utilized in areas such as parking lots, sidewalks, and pedestrian paths, where the traffic load is generally light (Haselbach et al., 2006). Fig. 2.5 illustrates the schematic cross-section of a typical pervious concrete pavement.

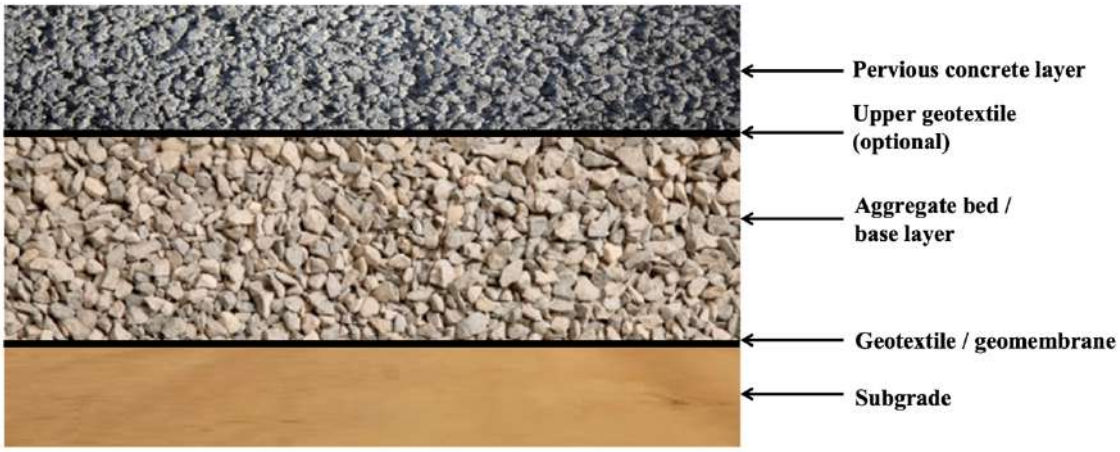


Fig. 2.5: Schematic cross-section of pervious concrete pavement
(Chandrappa and Biligiri, 2016)

ii) Pervious Asphalt Pavement: Porous asphalt pavement, akin to conventional asphalt but featuring a reduced proportion of fine aggregates, possesses interconnected voids that facilitate water infiltration. It is extensively utilized in road shoulders, residential streets, and highways subject to controlled traffic (Maia et al., 2024). Utilizing polymer-modified binders in porous asphalt improves its durability and crack resistance. Fig. 2.6 illustrates the schematic cross-section of a typical pervious asphalt pavement.

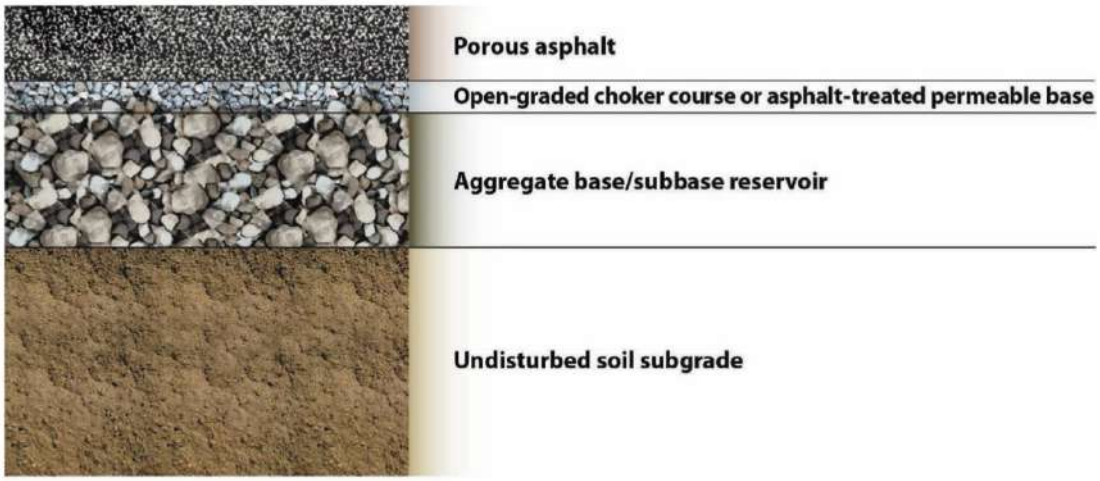


Fig. 2.6: Schematic cross-section of pervious asphalt pavement (Bruinsma et al., 2017)

2.3.3 Environmental and Economic Benefits

The adoption of pervious pavement presents notable environmental and economic advantages, establishing it as a sustainable alternative to conventional pavement systems.

From an environmental perspective, pervious pavements contribute to stormwater management by reducing runoff and allowing groundwater recharge, which helps maintain natural hydrological cycles (Pratt et al., 1995). Furthermore, they filter pollutants, including oils, heavy metals, and sediments, thus enhancing water quality prior to its discharge into natural water bodies. Additionally, pervious pavements assist in alleviating the urban heat island effect, as they retain less heat in comparison to traditional asphalt surfaces (Liu et al., 2020). Moreover, pervious pavements facilitate the use of recycled materials, including waste polyethylene and rubber, thereby lowering the environmental impact of pavement construction and encouraging sustainable material reuse.

From an economic perspective, pervious pavement significantly reduces infrastructure costs by minimizing the necessity for extensive stormwater drainage systems. Furthermore, it diminishes maintenance expenses by mitigating surface deterioration and preventing water-related damage. Although the initial installation costs may be marginally greater than those associated with traditional pavements, the long-term financial benefits derived from reduced flooding, enhanced road durability, and lower maintenance requirements render pervious pavements a financially prudent solution for sustainable urban development (Martins Vaz et al., 2020). Additionally, the aesthetic and functional benefits of pervious pavements can increase property values and urban attractiveness, making them an investment in both environmental health and economic resilience.

2.4 POLYMER MODIFIED BITUMEN

2.4.1 Types of Polymers Used

Polymers have been extensively used to enhance the properties of bitumen for better performance during its service life. They play a crucial role in improving bitumen by increasing its mechanical properties, durability, and resistance to environmental factors. The addition of polymers to bitumen boosts its performance by increasing elasticity, reducing temperature sensitivity, and enhancing resistance to deformation and fatigue. Based on their chemical structure and interaction with bitumen, the polymers utilized for modification can be categorized into three main groups: elastomers, plastomers, and reactive polymers. Each of these polymers contributes unique properties to the modified bitumen, thereby affecting its workability, durability, and overall performance in pavement applications.

i) Elastomers: Elastomers are polymeric materials with rubber-like characteristics. They provide bitumen with high elasticity and improved deformation recovery properties. These polymers increase bitumen's ability to withstand repeated loading cycles, thus reducing permanent deformation and fatigue-induced cracking (Senise et al., 2017). The key elastomeric polymers utilized in the modification of bitumen are:

a) Styrene-Butadiene-Styrene (SBS): SBS represents the most extensively utilized elastomer in bitumen modification. It forms a three-dimensional network within the bitumen, thereby improving its elasticity, thermal stability, and resistance to deformation and cracking. Bitumen modified with SBS demonstrates enhanced performance across both high and low temperature ranges, rendering it appropriate for use in extreme climatic conditions (Chen et al., 2002). However, the effectiveness is influenced by the polymer content (commonly ranging from 3% to 7% by weight), the mixing conditions, and the characteristics of the base bitumen.

Because of its exceptional performance, SBS-modified bitumen is widely used in high-traffic roadways, airport runways, and bridge decks, where durability and flexibility are crucial. While its initial cost is higher, it provides significant economic benefits in the long run by reducing maintenance needs and extending the pavement's lifespan (Omrani et al., 2017).

b) Styrene-Butadiene Rubber (SBR): SBR is a synthetic elastomer frequently employed to modify bitumen, particularly to enhance its adhesion, elasticity, and resistance to moisture damage. In contrast to Styrene-Butadiene-Styrene (SBS), SBR does not possess thermoplastic characteristics; however, due to its substantial rubber content, it significantly improves the flexibility and

durability of bitumen (Yildirim, 2007). When incorporated into bitumen, Styrene-Butadiene Rubber (SBR) significantly enhances resistance to fatigue cracking, thermal cracking, and stripping induced by moisture. It improves low-temperature performance by augmenting elasticity and mitigates premature aging by diminishing susceptibility to oxidation (Oliviero Rossi et al., 2015). Furthermore, the inclusion of SBR enhances the workability of asphalt mixtures, rendering it a favored option for cold-mix applications and recycled asphalt pavements (Polacco et al., 2015).

SBR-modified bitumen is frequently utilized in highway pavements, airport runways, and bridge decks, especially in areas characterized by substantial temperature fluctuations. Furthermore, given that Styrene-Butadiene Rubber (SBR) is typically sourced from recycled rubber materials, such as waste tires, its application promotes sustainability and enhances cost-effectiveness in pavement construction (Omrani et al., 2017).

c) Natural Rubber (NR): Natural rubber (NR), sourced from the latex of *Hevea brasiliensis* trees, serves as an elastomer in bitumen modification. It is a sustainable and environmentally friendly substitute for synthetic polymers like Styrene-Butadiene-Styrene (SBS) and Styrene-Butadiene Rubber (SBR). With its superior elasticity, flexibility, and resistance to environmental stress, natural rubber is an excellent modifier for bitumen, especially for enhancing pavement performance across different climatic conditions.

The incorporation of elongated polymer chains into natural rubber enhances the deformability of bitumen, thereby making it less susceptible to cracking due to thermal fluctuations. Furthermore, natural rubber modifies the viscoelastic properties of bitumen by reducing its brittleness at low temperatures

and preventing softening at elevated temperatures (Yildirim, 2007). Natural rubber-modified bitumen is used for constructing highway pavements, cold climate road surfaces, and in maintenance tasks like crack sealing. Its renewable nature renders it an environmentally sustainable option, thereby contributing to the principles of sustainable road construction (Lo Presti, 2013).

d) Ethylene Propylene Diene Monomer (EPDM): Ethylene Propylene Diene Monomer (EPDM) is a synthetic rubber frequently utilized for bitumen modification due to its outstanding resistance to aging, heat, and oxidative stress. EPDM is a terpolymer made up of ethylene, propylene, and a diene monomer, providing superior durability and elasticity. EPDM-modified bitumen is especially advantageous in environments where high durability and resistance to environmental stress are essential. EPDM-modified bitumen exhibits a high degree of resistance to ultraviolet degradation and weathering, which renders it particularly suitable for application on road surfaces subjected to severe environmental conditions (Lu and Isacsson, 1997).

EPDM-modified bitumen is commonly used in high-performance pavements, particularly for roads, airport runways, and areas subject to extreme temperature fluctuations. Thanks to its resilience against water and diverse weather conditions, it is also effective for roofing and waterproofing. Although the initial price of EPDM-modified bitumen might be higher than that of standard bitumen, its ability to prolong pavement lifespans and lessen maintenance expenses yields long-term economic advantages. Furthermore, EPDM is a non-toxic and eco-friendly material, supporting sustainable construction practices.

ii) Plastomers: Plastomeric polymers are mainly utilized to improve the stiffness and high-temperature performance of bitumen. Unlike elastomers,

plastomers do not greatly enhance elasticity but offer increased resistance against deformation from heavy traffic loads (Al-Mansob et al., 2014). The plastomers that are frequently employed in the modification of bitumen include:

a) Polyethylene (PE): PE constitutes one of the most extensively utilized polymers in the modification of bitumen, attributed to its capability to improve the stiffness, strength, and thermal stability of asphalt mixtures. PE is classified as a thermoplastic polymer and is available in various forms, predominantly Low-Density Polyethylene (LDPE), High-Density Polyethylene (HDPE), and Linear Low-Density Polyethylene (LLDPE), each providing distinct advantages in the context of bitumen modification (García-Morales et al., 2007).

The modification of polyethylene (PE) substantially improves the performance characteristics of bitumen, particularly in terms of rutting resistance, thermal stability, durability, and moisture resistance. The incorporation of PE elevates the stiffness of bitumen, thereby mitigating permanent deformation when subjected to substantial traffic loads and elevated temperatures (Moghaddam et al., 2011). Additionally, it elevates the softening point, rendering the pavement less prone to thermal degradation in warm climates (Zhang et al., 2019). PE-modified bitumen demonstrates improved fatigue resistance, thereby mitigating cracking and prolonging the lifespan of pavement. Additionally, the hydrophobic characteristics improve the bond between the binder and aggregates, thus decreasing the chances of stripping and moisture-related damage, which is vital for pavement durability in wet conditions (Modarres and Hamedi, 2014). One major benefit of polyethylene-modified bitumen is its ability to enhance the recycling of polyethylene and plastic waste. Recycled polyethylene, which includes used plastic bags and

bottles, may be integrated into bitumen, thus aiding in the mitigation of plastic pollution and fostering sustainable road construction practices (Ma et al., 2021).

b) Polypropylene (PP): Polypropylene (PP) is a type of thermoplastic polymer that greatly improves the stiffness, strength, and high-temperature resistance of bitumen, making it a popular choice for modifying asphalt mixtures. Thanks to its semi-crystalline structure and high melting point, PP significantly boosts the rigidity of bitumen, enhancing its load-bearing ability and resistance to permanent deformation when subjected to heavy traffic conditions (Zhu et al., 2014). However, because of its limited compatibility with bitumen, creating a uniform and stable blend typically necessitates the use of compatibilizers or additional processing methods, like reactive mixing or coupling agents, to improve polymer dispersion (Yang et al., 2024).

The incorporation of polypropylene (PP) into bitumen provides numerous performance advantages, such as improved resistance to rutting, enhanced thermal stability, and increased durability. Polypropylene elevates the softening point of bitumen, rendering it less prone to deformation at elevated temperatures, which is especially advantageous in warmer climates (Tapkın, 2008). Additionally, PP-modified bitumen shows enhanced resistance to oxidation and aging, which reduces the rate of pavement deterioration and prolongs its service life. On the other hand, it's important to note that PP can become quite rigid in colder temperatures, which might make it more prone to brittleness and cracking in chilly environments. Thankfully, this challenge can be easily addressed by blending PP with more flexible elastomeric polymers like styrene-butadiene-styrene (SBS) or by incorporating special additives to enhance its flexibility (Al-Hadidy and Yi-qiu, 2009).

c) Ethylene Vinyl Acetate (EVA): Ethylene Vinyl Acetate (EVA) is a copolymer composed of ethylene and vinyl acetate, commonly employed in the modification of bitumen due to its exceptional flexibility, toughness, and thermal stability. Bitumen that has been modified with EVA demonstrates enhanced elasticity and improved resistance to deformation when exposed to elevated temperatures, rendering it suitable for road pavements that endure heavy traffic and extreme weather conditions. The performance of EVA in bitumen primarily depends on the vinyl acetate (VA) content; higher VA levels enhance flexibility and adhesion, while lower VA content increases stiffness and load-bearing capacity (Yan et al., 2021).

The modification of ethylene-vinyl acetate (EVA) significantly enhances the rutting resistance, fatigue life, and low-temperature cracking resistance of bitumen, thereby extending the lifespan of asphalt pavements. The copolymer further improves the storage stability of bitumen by minimizing phase separation, thereby ensuring a more homogeneous blend during both mixing and paving processes (Brovelli et al., 2013). EVA also raises the softening point of bitumen, enhancing its resistance to deformation at high temperatures while ensuring sufficient flexibility to avoid cracking at lower temperatures. However, EVA-modified bitumen may require additional stabilizers or compatibilizers to enhance dispersion and prevent degradation over time. Notwithstanding these challenges, EVA is extensively utilized as a polymer in modified bitumen owing to its balanced mechanical properties and cost-effectiveness.

d) Polyvinyl Chloride (PVC): Polyvinyl Chloride (PVC) is a thermoplastic polymer utilized in modifying bitumen to enhance its stiffness, thermal stability, and resistance to deformation. PVC significantly enhances the viscoelastic characteristics of bitumen, thereby increasing its resistance to rutting at elevated

temperatures while preserving flexibility at lower temperatures. However, due to its limited compatibility with bitumen, additional processing techniques such as reactive blending or the use of plasticizers are often required to ensure uniform dispersion (Behl et al., 2014).

PVC-modified bitumen provides enhanced fatigue resistance, durability, and moisture resistance, making it ideal for heavy-duty pavements and waterproofing applications. Moreover, incorporating recycled PVC waste into bitumen offers an environmentally friendly solution, reducing plastic waste and promoting sustainability (Fakhri et al., 2022). However, the elevated melting point of polyvinyl chloride (PVC) and its susceptibility to thermal degradation necessitate meticulous temperature regulation during the mixing process to avert polymer disintegration and the release of hazardous gases (Lo Presti, 2013).

iii) Reactive Polymers: Reactive polymers engage in chemical interactions with bitumen, leading to the establishment of stable chemical bonds that enhance the binder's homogeneity and long-term stability. These polymers not only enhance the physical properties of bitumen but also improve its resistance to aging and adhesion characteristics (Polacco et al., 2015). The widely used reactive polymers in bitumen modification include:

a) Polyurethane (PU): Polyurethane (PU) is a versatile polymer used to modify bitumen to enhance its elasticity, durability, and resistance to aging. Bitumen modified with PU demonstrates superior fatigue resistance, thermal stability, and flexibility, rendering it suitable for application in both hot and cold climates (Wu et al., 2024). The incorporation of PU improves the adhesion between aggregates and binders, minimizing stripping and moisture damage, which is essential for durable pavements (Chen et al., 2024).

The modification of polyurethane (PU) significantly enhances rutting resistance, low-temperature cracking resistance, and oxidation resistance, thereby extending the service life of pavements. Furthermore, PU-modified bitumen has self-healing capabilities, allowing for the recovery of microcracks under load cycles, which ultimately leads to improved durability of the pavement (Zhang et al., 2020). However, the high cost and sensitivity to processing conditions necessitate optimized formulations to balance performance and economic feasibility.

b) Epoxy Resin (ER): Epoxy resin is a type of plastic that hardens when heated. It's often used to improve bitumen, a key material in road construction. By adding epoxy resin, we can make bitumen stronger, longer lasting, and better at handling changes in shape under stress. This modification creates a solid and interconnected structure within the bitumen, greatly enhancing its stiffness, life span against wear, and ability to withstand temperature changes. The incorporation of epoxy resin improves adhesion between binder and aggregates, reducing stripping and moisture-induced damage. Additionally, epoxy-bitumen mixtures exhibit higher tensile strength and longer service life compared to conventional binders (He et al., 2021). Nonetheless, while the costs are higher and the mixing process is complex, it's essential to make thoughtful adjustments in formulation to enhance both performance and cost-effectiveness.

2.4.2 Benefits of Polymer Modification of Bitumen

The primary objective of polymer modification of bitumen is to produce more durable pavements characterized by increased stiffness and stability, which ultimately contribute to a reduction in maintenance costs. Although the incorporation of polymers may occasionally elevate construction expenses, the significant advantage resides in the enhanced quality of the pavement. For

instance, the utilization of materials such as recycled polyethylene (RPE) and crumb rubber (CR) not only improves the quality of the pavement but also promotes cost-effectiveness. The advantages of polymer-modified bitumen (PMB) can be evaluated through three principal criteria: enhanced performance, long-term durability, and overall economic value.

Quality Improvement of Binder: Polymers significantly enhance the quality of bitumen, improving its overall performance in asphalt pavements. The inclusion of polymers leads to several key improvements:

- **Increased Viscosity:** Polymers elevate the binder's viscosity, facilitating the formation of a thicker film in paving mixtures. This improvement helps mitigate excessive drainage and bleeding, thereby ensuring that the binder retains its stability throughout mixing and application (Zhu et al., 2024).

- **Enhanced Crack Resistance:** The modification improves the binder's capacity to resist cracking, particularly under dynamic deformation. This enhancement is essential for managing the stresses and movements within the pavement's internal layers, thereby contributing to an extension of the pavement's lifespan (Jwaida et al., 2024).

- **Improved Fatigue Resistance:** The modification of polymers enhances the mechanical resistance of the binder, particularly with respect to tensile forces. This enhances its capacity to endure repetitive loading, thereby significantly improving its fatigue resistance and decreasing the probability of premature cracking (Jwaida et al., 2024).

- **Higher Softening Point:** Polymers raise the binder's softening point, reducing the risk of bleeding at high temperatures. This ensures that the pavement remains stable and resistant to deformation even in hot climates or under heavy traffic (Yildirim, 2007).

- **Enhanced Elasticity and Resilience:** Polymers enhance the elasticity and resilience of bitumen at elevated temperatures, enabling the binder to revert to its original form after deformation. This improves the pavement's overall flexibility, lowering the chances of cracks or damage in high thermal conditions (Yildirim, 2007).

- **Reduced Fraass Breaking Point:** The modification lowers the Fraass breaking point temperature, thereby enhancing the binder's flexibility in lower temperature conditions and diminishing the potential for cracking in colder environments (Wang et al., 2017).

- **Increased Cohesion:** Polymers enhance the cohesion of the binder, thereby ensuring improved adhesion to the aggregates. This improvement significantly elevates the overall integrity and performance of the asphalt mixture, particularly under wet or adverse conditions (Yildirim, 2007).

- **Reduced Thermal Susceptibility:** Polymer-modified bitumen shows decreased susceptibility to thermal fluctuations at both high and low temperatures. This characteristic enhances pavement performance under various climatic conditions, ensuring that the binder retains flexibility in cold temperatures and resists deformation in high temperatures (Osman et al., 2024).

- **Rejuvenation of Aged Asphalt:** Polymers can also rejuvenate aged asphalt binders, enhancing their elasticity and restoring their original properties. This is particularly advantageous for extending the service life of pavements that have deteriorated over time due to oxidation and weathering (Mashaan and Dassanayake, 2025).

These improvements together enhance the durability, performance, and cost-efficiency of polymer-modified bitumen, positioning it as an excellent option for creating long-lasting, high-performance pavements.

Improvement in Pavement Performance: Significant improvements in pavement performance can be achieved through polymer modification, including:

- Enhanced flexibility, allowing the pavement to better withstand temperature fluctuations and traffic loads.
- Reduced deformation, helping the pavement maintain its structure and integrity over time.
- Improved resistance to aging and oxidation results from higher binder content, thicker binder films, and the addition of antioxidants derived from recycled tire rubber.
- Increased fatigue resistance allows the pavement to withstand repetitive traffic loading without cracking or premature wear.
- Better resistance to stripping, ensuring the binder stays adhered to the aggregates, especially in wet conditions.
- Self-healing properties enable minor cracks to close over time, which extends the pavement's lifespan.

- Greater durability results in pavements that last longer and perform better under heavy traffic and harsh weather conditions.
- Lower maintenance costs arise from the improved durability and performance of the pavement, decreasing the necessity for frequent repairs or resurfacing.
- Shorter construction times can be achieved by utilizing thinner layers, which accelerates the paving process.

In surface treatment, several performance benefits can be achieved, including:

- Improves abrasion resistance, contributing to a decrease in other forms of surface degradation, thereby prolonging the pavement's lifespan.
- Reduced cracking and rutting, improving the overall durability and structural integrity of the surface.
- Decrease bleeding to maintain a stable and consistent surface while minimizing binder loss.
- Increased skid resistance, making the pavement safer for vehicles, especially in wet conditions.
- Long-lasting color contrast, maintaining clear and visible markings for better road visibility and safety over time.
- Noise reduction creates a quieter driving experience by reducing traffic-related noise.
- Greater stress absorption enables the surface to handle heavy loads and vibrations without damage.
- Enhances impermeability, preventing water from penetrating the pavement, thereby reducing moisture-related damage.

Environmental Improvement: The modification of bitumen through polymer addition and surface treatments not only enhances the performance of pavements but also plays a crucial role in promoting environmental sustainability. These technologies offer numerous benefits that reduce the environmental impact linked to road construction and maintenance, in line with both global and national initiatives aimed at promoting sustainable infrastructure development.

- **Reduction in Carbon Footprint:** The utilization of recycled materials, including recycled polyethylene (RPE) and crumb rubber (CR), in the modification of bitumen significantly diminishes the demand for virgin materials. This reduction subsequently decreases the carbon footprint linked to production and transportation, thereby fostering a more sustainable construction process (Fernandes et al., 2017). Additionally, incorporating waste materials into polymer-modified bitumen helps lessen the environmental impact of landfilling while also supporting the ideals of a circular economy. In Bangladesh, where waste management challenges are growing more severe, this method complements efforts to minimize polyethylene waste and repurpose it to improve infrastructure development.

- **Waste Reduction:** Incorporating recycled tire rubber into bitumen not only helps tackle the growing issue of tire waste but also addresses the environmental challenges associated with tire disposal. Countries such as Bangladesh are grappling with significant problems stemming from the increasing number of discarded tires, which puts a strain on their waste management systems. By using tire rubber in asphalt, we can prevent these waste products from ending up in landfills and transform them into valuable resources for infrastructure projects (Ghafari et al.,

2023). This approach not only promotes environmental conservation but also reduces the adverse effects of improper tire disposal on our surroundings.

- **Energy and Resource Efficiency:** The use of polymer-modified bitumen and advanced surface treatments makes it possible to create thinner asphalt layers and speeds up construction. This innovation leads to lower energy usage and a reduced need for raw materials, ultimately decreasing the environmental impact of building projects. In Bangladesh, where the construction sector is expanding quickly, incorporating resource-efficient materials and methods plays a crucial role in lessening the environmental effects of urban growth and infrastructure development.

- **Reduction in Urban Heat Island Effect:** Pavements enhanced with polymer-modified bitumen and specific surface treatments show improved reflective properties that help alleviate the urban heat island effect. This is especially crucial in heavily populated regions like Dhaka and Chattogram, where dark asphalt surfaces can exacerbate high temperatures. The increased reflectivity of these treated pavements contributes to lowering ambient temperatures, fostering more comfortable urban spaces, and decreasing the need for energy-intensive cooling solutions.

- **Water Management:** Certain types of surface treatments, especially pervious pavements, really boost the ability of the ground to absorb water while decreasing surface runoff. This is particularly important in places like Bangladesh, where the heavy rains and frequent monsoon seasons can lead to severe flooding and waterlogging in cities. Pervious pavements are crucial for improving stormwater management by

enabling greater water infiltration and decreasing runoff. They also help ease the pressure on drainage systems and enhance the overall quality of water in the surrounding environment (Sartipi and Sartipi, 2019).

- **Longevity and Lower Maintenance Costs:** Polymer-modified bitumen and surface treatments effectively extend pavement life. They reduce the need for regular resurfacing and repairs, ultimately leading to fewer construction projects. This reduction not only saves resources but also lessens the overall environmental impact related to material production, transportation, and construction activities. In Bangladesh, where road maintenance is frequently postponed due to budget limitations and logistical challenges, these solutions can greatly improve the sustainability of the nation's road infrastructure.

Overall, the benefits of polymer-modified bitumen and surface treatment technologies play a vital role in promoting sustainable infrastructure development, not only around the world but also specifically in Bangladesh. These innovative solutions help reduce waste, decrease carbon emissions, enhance energy efficiency, and improve water management. All these factors contribute to creating a greener and more sustainable future for urban infrastructure.

2.4.3 Applications in Pavement Construction

Polymer-modified bitumen (PMB) and surface treatments have become essential in pavement construction, largely due to their remarkable improvements in performance and sustainability. These materials significantly contribute to enhancing durability and safety, while also reducing the environmental impact of pavements. They are utilized in a multitude of

applications, including but not limited to highways, airport runways, industrial roads, and specialized pavements, all of which derive significant advantages from the exceptional properties of Polymer Modified Bitumen (PMB).

2.4.3.1 Roadways and Highways

Polymer-modified bitumen (PMB) is primarily used in the construction of highways and urban roads. Highways endure heavy traffic, extreme weather conditions, and continuous wear, making them susceptible to problems like rutting, cracking, and fatigue. PMB enhances the viscosity of bitumen, enabling it to create thicker films that help prevent bleeding and rutting. Polymers like SBS (styrene-butadiene-styrene) and SBR (styrene-butadiene rubber) improve the binder's mechanical properties, providing increased durability and crack resistance to handle varying traffic loads and temperatures. In urban environments, PMB also enhances skid resistance, promoting road safety by offering better traction, particularly in wet conditions. Fig. 2.7 shows an example of PMB being used in roadway construction.



Fig. 2.7: A road in Australia made with PlastiPhalt®- a commercial polymer-modified bitumen ("PlastiPhalt® – ISCouncil," n.d.)

2.4.3.2 Heavy Traffic and Industrial Roads

Industrial roadways and areas characterized by heavy traffic derive significant advantages from PMB's improved resistance to permanent deformation. Roadways situated in logistics hubs, warehouses, and truck routes are subjected to continuous, substantial loads, which may result in cracking, rutting, and deterioration of the surface. PMB enhances the fatigue resistance and chemical stability of asphalt, thereby ensuring its capability to endure these severe conditions. Polymers such as SBR and EPDM (ethylene propylene diene monomer) enhance binder cohesion, mitigating moisture-induced stripping and damage resulting from substantial traffic loads (Ghafari et al., 2023).

2.4.3.3 Airport Runways

PMB plays a critical role in constructing airport runways. These surfaces must endure the heavy weight of aircraft and harsh environmental conditions. By using PMB, we enhance thermal stability, fatigue resistance, and crack resistance, which ensures that runways can manage high temperatures without warping or deforming. The addition of SBS polymer is particularly beneficial because it maintains performance even in heat, effectively preventing rutting caused by aircraft movements. In regions with cold climates, PMB's flexibility becomes essential, as it helps mitigate cracking during freeze-thaw cycles. Furthermore, PMB is also utilized in resurfacing existing runways, which not only extends their lifespan but also lowers maintenance costs. Polymer-modified bitumen has been recently used to strengthen Shah Amanat International Airport in Chattogram. The construction of the runway's wearing course is shown in Fig. 2.8.



Fig. 2.8: Polymer Modified Bitumen used in wearing course of the Shah Amanat International Airport, Chattogram (Mir Akhter Hossain Limited, n.d.)

2.4.3.4 Pervious Pavements and Sustainability

The utilization of pervious pavements represents another significant application of Polymer Modified Bitumen (PMB). Pervious pavements facilitate the infiltration of water through their surface, thereby diminishing surface runoff and decreasing the risk of flooding, especially in urban areas that are susceptible to heavy rainfall. PMB serves to preserve the permeability of the pavement surface while simultaneously enhancing moisture resistance, rendering it particularly suitable for stormwater management systems. This practice contributes to environmental sustainability by decreasing the presence of impermeable surfaces, enhancing water quality, and alleviating the urban heat island effect (Sartipi and Sartipi, 2019).

The role of permeable materials in managing stormwater is becoming increasingly important in countries such as Bangladesh, where frequent monsoons create significant flooding risks. By improving water infiltration and

durability, pervious pavements play a key role in reducing the likelihood of flooding and enhancing the resilience of urban infrastructure.

2.5 WASTE POLYETHYLENE IN PAVEMENT CONSTRUCTION

The growing accumulation of waste polyethylene has become a major global environmental concern, significantly affecting ecosystems and urban sustainability. Considering this challenge, researchers and engineers have investigated innovative strategies to integrate waste polyethylene into pavement construction. By incorporating recycled polyethylene into bituminous mixtures, pavement performance can be enhanced while concurrently reducing environmental pollution. This section examines the various types and sources of waste polyethylene, its incorporation into bitumen, and the environmental and economic advantages associated with recycling waste polyethylene for pavement construction.

2.5.1 Applications in Pavement Construction

Polyethylene (PE) is one of the most used types of synthetic plastic. You can find it everywhere: in packaging, consumer products, and various industrial uses. While its durability and resistance to breaking down make it a popular choice, the resulting polyethylene waste has become a significant environmental issue, piling up in landfills and polluting water bodies. Therefore, managing this waste effectively is essential for sustainable practices. One promising solution is to incorporate waste polyethylene into the construction of pavements. Depending on its molecular structure and density, waste polyethylene can be divided into different types, each possessing unique characteristics that can enhance its reuse in asphalt mixtures. The following are the commonly available types of polyethylene in the waste:

2.5.1.1 Types of Waste Polyethylene

i) Low-Density Polyethylene (LDPE): LDPE is a flexible and lightweight polymer often used in the production of polyethylene bags, food packaging films, and squeeze bottles. Due to its prevalent application in single-use products, LDPE constitutes a substantial proportion of plastic waste. Its relatively low melting point, combined with its high elongation characteristics, renders it appropriate for incorporation into bitumen, enhancing flexibility and mitigating pavement cracking (Muringayil Joseph et al., 2024).

ii) High-Density Polyethylene (HDPE): HDPE is a more rigid and durable variant of polyethylene commonly used in plastic bottles, pipes, and industrial containers. It offers superior tensile strength and chemical resistance, making it an ideal option to enhance the stiffness and load-bearing strength of asphalt pavements (Jwaida et al., 2023).

iii) Linear Low-Density Polyethylene (LLDPE): LLDPE is similar to LDPE but stands out with greater tensile strength and enhanced puncture resistance. This versatile material is mainly utilized in agricultural films, industrial wrapping, and geomembranes. Additionally, when used in pavement materials, it has been shown to enhance fatigue resistance and decrease moisture susceptibility, making it valuable in various applications (Nafiu et al., 2025).

2.5.1.2 Sources of Waste Polyethylene

Waste polyethylene is produced by various sectors, significantly contributing to plastic waste streams in both municipal and industrial settings. Key sources include:

i) Household Waste: Single-use polyethylene bags, food packaging, detergent containers, and discarded plastic bottles significantly contribute to the domestic polyethylene waste problem. In cities, poor waste management exacerbates this issue, leading to increased environmental pollution (Abdullah and Abedin, 2024).

ii) Industrial and Commercial Waste: Manufacturing industries produce substantial amounts of polyethylene waste, such as faulty packaging and discarded plastic parts. Mismanagement of this waste frequently leads to contamination of land and water.

iii) Agricultural Sector: The utilization of polyethylene films for mulching, greenhouse covers, and irrigation pipes contributes to a considerable accumulation of polyethylene waste in rural regions. Recycling this waste into pavement materials has the potential to diminish agricultural polyethylene pollution substantially (Abdullah and Abedin, 2024).

iv) Municipal Solid Waste (MSW): In Bangladesh, plastic waste constitutes approximately 8% of total MSW, with polyethylene-based materials accounting for nearly 60% of the plastic fraction. Without proper disposal and recycling measures, this waste contributes to severe environmental degradation, including clogged drainage systems and urban flooding (Abdullah and Abedin, 2024).

2.5.2 Integration of Waste Polyethylene in Bitumen

The incorporation of waste polyethylene into bitumen represents a promising strategy for enhancing pavement quality and reducing environmental impact pollution. Several techniques have been devised for integrating

polyethylene into bitumen, each providing distinct advantages regarding mechanical properties, durability, and sustainability. The key modification methods consist of the wet process and dry process, with each necessitating particular steps for proper blending and application. The modification methods are briefly described below:

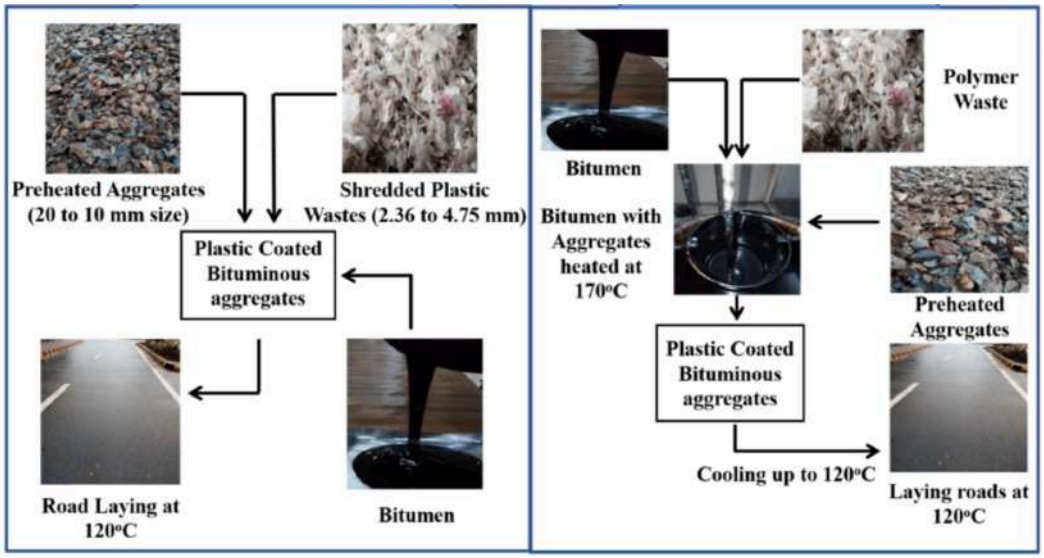
2.5.2.1 *Dry Process*

The dry process, on the other hand, involves directly blending waste polyethylene with hot aggregates before adding bitumen. This process coats the aggregate surface with plastic, improving the interlocking of aggregates and strengthening the pavement's structural integrity (Kibria et al., 2023). Waste polyethylene is first collected and meticulously cleaned before being shredded into small flakes or pellets. The aggregates are then elevated to a high temperature, usually between 170 to 190 degrees Celsius, to facilitate adhesion. Next, the shredded polyethylene is added to the heated aggregates and mixed thoroughly to achieve an even coating prior to adding the bitumen binder, culminating in the final asphalt mix. This dry process is cost-effective and reduces the risk of polymer degradation during mixing. It has been successfully used in numerous road construction projects throughout India, showcasing its ability to improve pavement performance with minimal alterations to existing equipment (Raut et al., 2016). Fig. 2.9 (a) shows the dry process flow diagram.

2.5.2.2 *Wet Process*

The wet process entails the direct incorporation of waste polyethylene into heated bitumen prior to its amalgamation with aggregates. This methodology guarantees a uniform modification of the binder, enhancing its elasticity, resistance to rutting, and overall performance of the pavement (Raut et al., 2016). In this process, waste polyethylene materials, including plastic bags, bottles, and

packaging films, are collected and subsequently cleaned to eliminate impurities. The purified polyethylene is then processed into small granules, typically ranging from 1 to 5 mm in size, to improve uniform dispersion within the bitumen (Zhou et al., 2021). Hot bitumen, usually heated to between 160 and 180°C, gradually receives these granules. They are stirred continuously for 30 to 60 minutes to achieve thorough mixing (Purohit et al., 2022). After blending, the modified bitumen is kept at a regulated temperature prior to mixing with aggregates to create asphalt concrete. Fig. 2.9 (b) shows the wet process flow diagram. This wet process ensures consistent bitumen modification, resulting in better flexibility, decreased temperature sensitivity, and increased pavement durability.



(a) (b)

Fig. 2.9: (a) Dry and (b) Wet process for plastic road manufacturing (Gill and Abid, 2019)

2.5.3 Environmental and Economic Benefits of Recycled Waste Polyethylene

Using recycled waste polyethylene in pavement construction represents a sustainable strategy for addressing polyethylene pollution while also enhancing road performance. This approach not only addresses the environmental risks

associated with polyethylene-plastic waste buildup but also offers economic advantages by lowering construction costs and generating jobs. In Bangladesh, where the management of polyethylene waste constitutes a significant challenge, the incorporation of waste polyethylene into road construction offers a feasible solution for both the advancement of infrastructure and the promotion of environmental sustainability.

2.5.3.1 *Environmental Benefits*

The use of recycled polyethylene in bituminous mixtures significantly reduces polyethylene pollution by diverting non-biodegradable waste from landfills and waterways. Due to inadequate waste management systems, a significant part of this polyethylene ends up in drainage systems, rivers, and coastal areas, leading to severe environmental degradation (Jambeck et al., 2015). Integrating this waste into pavement construction contributes to the reduction of land and marine pollution, thus fostering the development of cleaner urban environments and ecosystems.

The recycling of polyethylene for road construction additionally contributes to a reduction in carbon emissions by lessening the reliance on virgin bitumen, which is obtained from crude oil. The process of bitumen production is characterized by its high energy consumption and significantly contributes to greenhouse gas emissions (Farina et al., 2023). By integrating waste polyethylene into bitumen, road construction projects can reduce their carbon impact and prolong pavement durability. Research indicates that this polyethylene-modified bitumen improves resistance to rutting, moisture damage, and cracking. Consequently, it decreases the need for road repairs and reconstruction, leading to lower resource usage (Hao et al., 2024).

Another notable environmental benefit is the increased durability and impermeability of pavements modified with polyethylene. Roads constructed using polyethylene waste demonstrate superior resistance to water infiltration, thereby minimizing the occurrence of potholes and mitigating structural damage induced by heavy rainfall and flooding. This is especially significant for Bangladesh, where the monsoon season and inadequate drainage systems lead to the rapid deterioration of road pavements. Enhancing the durability of roads reduces the need for raw materials like aggregates and bitumen, thereby supporting better resource conservation.

2.5.3.2 *Economics Benefits*

The integration of waste polyethylene in pavement construction presents substantial economic advantages. A primary benefit is the potential for cost reductions in road construction. By replacing a portion of bitumen with waste polyethylene, the overall material expenses are diminished. With the rising global costs of bitumen, incorporating waste polyethylene as a partial alternative can greatly reduce the costs related to road infrastructure projects. This is especially beneficial for developing countries like Bangladesh, where government funding for road upkeep is frequently limited.

Additionally, the use of polyethylene-modified bitumen enhances the longevity of reduces maintenance expenses. In Bangladesh, traditional asphalt pavements often need timely resurfacing and repairs because of the quick deterioration caused by heavy traffic and harsh weather conditions (Kibria et al., 2023). Roads constructed with polyethylene-modified asphalt are demonstrating significantly greater durability. As a result, they require fewer repairs over time, leading to cost savings on the long-term maintenance of our infrastructure.

Beyond cost savings, recycling waste polyethylene into road construction promotes job creation and economic growth. The collection, sorting, and processing of polyethylene-plastic waste requires a labor force, thereby creating job opportunities in both formal and informal sectors ("The Economics of Plastic Waste: Costs and Opportunities | Bio-Tec Environmental," n.d.). This is particularly important for Bangladesh, where many people are involved in informal waste collection. Establishing structured recycling programs for using polyethylene in road construction can enhance livelihoods and promote a circular economy.

Additionally, the use of recycled polyethylene in road construction aligns well with Bangladesh's national goals for sustainable development. The government has been investigating ways to reduce polyethylene waste and encourage environmentally friendly infrastructure solutions. Promoting the use of polyethylene waste in building roads not only aids in waste management efforts but also reinforces Bangladesh's dedication to environmental sustainability on a global level.

2.6 PREVIOUS RESEARCH

Asphalt modification is a technique used to enhance the strength and durability of pavements. Below is a comprehensive review of the research pertinent to the current study.

(Hao et al. 2024) investigates the use of plastic waste in porous asphalt pavement as a sustainable alternative to conventional recycling methods. It examines the engineering effectiveness of plastic-modified porous asphalt, highlighting factors like rutting resistance, moisture sensitivity, cracking

susceptibility, and fatigue life. Results show that incorporating plastic waste improves rutting and stripping resistance, although excessive use may reduce abrasion resistance. The research also addresses environmental issues, especially regarding water resources, concluding that using plastic waste does not lead to aquatic pollution. Furthermore, a life cycle cost analysis (LCCA) reveals significant economic advantages, positioning this method as an effective strategy for managing plastic waste and promoting a circular economy.

(Gill and Abid, 2019) highlights the ecological consequences of plastic waste, primarily made up of non-biodegradable items like beverage containers, bags, and single-use products. Conventional disposal methods, such as incineration and landfill, carry additional environmental hazards, rendering them less effective solutions. Alternatively, incorporating plastic waste into flexible pavement construction using plastic-modified bitumen offers a more sustainable option. This method not only mitigates plastic waste but also improves road durability, water resistance, and lifespan. Characterization tests demonstrate that these "green roads" are economically viable and show enhanced thermal stability, positioning them as a feasible choice for sustainable infrastructure.

(Jwaida et al., 2023) investigates how waste polymers can be integrated into asphalt mixtures, presenting a sustainable method for enhancing pavement performance while tackling environmental issues. Research indicates that adding polymeric waste to asphalt enhances its durability and mitigates typical issues such as permanent deformation, thermal cracking, and fatigue damage. The study details various kinds of waste polymers, highlighting their benefits and the obstacles in their use. It also addresses considerations for mixture design and future research avenues. By reviewing various studies, this paper offers vital

insights into the viability and effectiveness of using polymer-modified asphalt, thereby supporting advancements in eco-friendly road construction practices.

(Dalhat and Al-Abdul Wahhab, 2017) conducted a study in Saudi Arabia about the use of recycled plastic waste, including polypropylene (PP), high-density polyethylene (HDPE), and low-density polyethylene (LDPE), in asphalt modification to improve pavement performance. Plastic waste was shredded and blended with asphalt binder to improve viscoelastic properties. All recycled plastic types enhanced rutting resistance, with PP-modified asphalt showing the highest resilient modulus (MR) increase at 55%, followed by HDPE at 19% and LDPE at 9%. The study found a link between the resilient modulus and the binder's non-recoverable creep compliance (Jnr). Mechanistic-empirical pavement design modeling revealed that adding recycled plastic waste significantly enhanced fatigue resistance and rutting performance. However, to meet the AASHTO TP 70 elastic recovery standard, the researchers suggested incorporating elastomeric polymers with recycled plastic waste.

(Hinislioglu and Agar, 2004) investigates the use of High-Density Polyethylene (HDPE) as a polymer additive in asphalt concrete. It examines the effects of varying HDPE content (4%, 6%, and 8% by weight of optimum bitumen), mixing temperatures (145–155°C and 165°C), and mixing times (5–15 and 30 minutes) on the Marshall Stability, flow, and Marshall Quotient (MQ). The results show that HDPE-modified asphalt significantly improves Marshall Stability and MQ, indicating enhanced resistance to deformation. The optimal conditions were found to be 4% HDPE, a mixing temperature of 165°C, and a mixing time of 30 minutes, with an MQ increase of 50% compared to the control mix. This approach not only enhances asphalt performance but also contributes to plastic waste recycling and environmental protection.

(Ma et al., 2021) finds that the use of waste plastics in hot mix asphalt (HMA) offers a sustainable solution for plastic waste management while enhancing pavement performance. Common plastic types in U.S. municipal solid waste include HDPE, LDPE, PP, PS, PET, EVA, and PVC. This review explored the use of waste plastics in asphalt mixtures through both wet and dry methods. The findings show enhancements in rutting, fatigue, and moisture resistance. Nevertheless, challenges such as compatibility issues and inadequate low-temperature performance persist. Solutions include the use of polymer and chemical additives, as well as nanomaterials. Future research should focus on aging effects, pavement performance monitoring, polymer stabilization, and economic and environmental impacts.

(Brasileiro et al., 2019) finds that the utilization of polymer-modified binders significantly enhances the performance of asphalt pavement; however, their elevated costs hinder broad implementation. Reclaimed polymers (RP) present a cost-effective alternative, contributing positively to durability and sustainability. This review conducts a comparative analysis of commonly utilized recycled polymers—namely polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), ethylene-vinyl acetate (EVA), and ground tire rubber (GTR)—evaluating their effects on mechanical behavior, mixing conditions, and stability. Plastomers are known to enhance stiffness and resistance to rutting, whereas elastomers, such as crumb rubber, improve elasticity. The combination of polyethylene and crumb rubber exhibits potential; however, further investigation is required to ascertain stability across varying temperatures. Additionally, additives such as maleic anhydride have been shown to enhance binder performance, although they may diminish the economic advantages associated with the use of recycled materials.

Earlier research demonstrates considerable progress in pavement engineering and sustainable materials. Utilizing pervious pavement technology, polymer-modified bitumen, and waste polyethylene offers a hopeful strategy for developing environmentally friendly and resilient infrastructure.

2.7 LABORATORY INVESTIGATION

The laboratory investigation concerning waste polyethylene-modified pervious asphalt pavement includes a series of tests designed to assess the mechanical, physical, and durability properties of the modified mixtures. The primary objective is to analyze the impact of waste polyethylene on the performance of pervious asphalt mixtures, with particular emphasis on attributes such as permeability, strength, and resistance to deformation.

2.7.1 Binder Quality

The quality of bituminous binders significantly influences the performance and longevity of asphalt pavements. Numerous researchers have underscored the necessity of assessing binder properties to ensure compliance with the stipulated performance criteria. Standard tests utilized for characterizing binder quality include measurements of penetration, softening point, ductility, and viscosity. These properties are evaluated in accordance with established procedures, specifically ASTM D5 (penetration), ASTM D36 (softening point), ASTM D113 (ductility), ASTM D4402 (viscosity), etc.

Research indicates that modified binders, particularly those utilizing waste polyethylene, provide substantial improvements in critical physical attributes compared to conventional 60/70 penetration grade bitumen. These binders often exhibit reduced penetration values, elevated softening points, and enhanced

viscosity, thereby demonstrating heightened resistance to deformation and thermal sensitivity (Roberts et al., 1996). These enhancements are imperative for road surfaces subjected to substantial traffic loads and extreme climatic conditions.

Benchmark values delineated in standards such as ASTM specifications and IRC: SP: 53-2010 are routinely employed to assess whether a binder, irrespective of being neat or modified, adheres to the mandated performance thresholds. Research has established that waste polyethylene-modified binders possess the capability to meet or exceed these standards, thereby offering enhanced durability and service life in comparison to traditional binders. Binder quality evaluation is essential for selecting materials for traditional and modified asphalt mixtures.

2.7.2 Mix Design for Pervious Pavement

The design mix for pervious asphalt pavement is a crucial step in achieving good performance, including permeability, strength, and durability. This process involves carefully selecting the right materials, finding the ideal binder content, and ensuring there are enough interconnected voids for proper water infiltration. To optimize the performance of pervious asphalt pavement, the mix design is based on guidelines from ASTM D7064, NCHRP reports, and the MS-2 Asphalt Mix Design Manual.

The choice of materials is essential for formulating a high-performance mix. Coarse aggregates, characterized by a proper gradation, are utilized to establish interconnected voids, which promote water infiltration while upholding the structural integrity of the mix. The use of fine aggregates is either restricted or eliminated to maintain porosity, thereby ensuring effective drainage.

Additionally, waste polyethylene-modified bitumen is integrated to improve durability and enhance resistance to rutting and moisture infiltration. To further optimize the mix's cohesion and overall performance, additives such as stabilizers or fibers may also be included.

The process of mix design commences with the selection of aggregate gradation to achieve the requisite air void content, which generally falls within the range of 15% to 25% to ensure adequate permeability. Subsequently, the binder content is determined through an iterative approach, which guarantees a balance among durability, stability, and permeability. The guidance provided by ASTM D7064 assists in the selection of the optimum binder content (OBC), typically within the range of 4% to 7% by weight of the aggregates. Modification of waste polyethylene is executed through either the wet or dry process; in the wet process, polyethylene is melted and blended with bitumen prior to amalgamation with the aggregates, whereas in the dry process, polyethylene is introduced directly to the aggregates before the application of the binder.

The prepared mixture undergoes controlled compaction within a temperature range of 150°C to 165°C, utilizing either a Marshall or gyratory compactor while minimizing the number of compaction blows to preserve the desired porosity. To assess the mix's performance, laboratory tests are performed, which include permeability tests for evaluating water infiltration capacity, Marshall Stability tests to determine strength, and moisture susceptibility tests aimed at confirming resistance to environmental degradation. By following these methods, the design of the pervious asphalt pavement mix is fine-tuned for long-term effectiveness, promoting efficient stormwater management and enhancing sustainability in pavement infrastructure.

2.7.3 Performance of Asphalt Pavement

A thorough series of laboratory tests is conducted to assess the performance of waste polyethylene-modified pervious asphalt pavement. The Indirect Tensile Strength (ITS) Test (ASTM D6931) assesses the tensile strength of the mixture, thereby facilitating an evaluation of its resistance to cracking, which is essential for the pavement's long-term durability. To ascertain the permeability of the mixture, the Permeability Test (ASTM PS129-01) is executed to measure the rate of water infiltration through the pavement, a critical aspect for ensuring effective stormwater management. Additionally, the Marshall Stability and Flow Test (ASTM D6927) is performed to assess the strength and deformation characteristics of the mixture, yielding insights into its resistance to rutting and deformation under heavy traffic conditions. Lastly, the Moisture Susceptibility Test (AASHTO T283) determines the impact of water on the adhesion between the bitumen and aggregates, which is vital for evaluating the performance of the mixture in wet conditions. Collectively, these tests provide valuable data that aids in optimizing te mix design, thereby ensuring enhanced durability, permeability, and structural stability for waste polyethylene-modified pervious asphalt pavement.

2.8 SUMMARY

After a thorough literature review presented in this chapter, the following key concluding remarks can be made:

1. The binder is to be modified with waste polyethylene to compare its properties with neat bitumen, and hence, it is needed to find out the suitable concentration of waste polyethylene for pavement construction through its mechanical and physical properties.

2. The optimal modified binder content is to be determined by the proper mix design method to ensure the enhancement of the performance of pervious asphalt pavement in terms of strength, durability, and permeability.
3. Water sensitivity analysis of neat and modified bituminous mixes is to be assessed in terms of retained stability, indirect tensile behavior, tensile strength ratio (TSR), etc.
4. The effectiveness of water infiltration rate through bituminous mixes prepared by waste polyethylene-modified binder and 60/70 binder is to be assessed for pervious asphalt pavement construction.

Chapter 3: MATERIALS AND METHODS

3.1 GENERAL

This chapter outlines the materials and methodologies used in the laboratory assessment of waste polyethylene-modified pervious asphalt pavement. The main materials include aggregates, bitumen, and waste polyethylene, which are combined to create pervious asphalt mixtures. Aggregates are carefully selected according to gradation specifications, while the bitumen is modified using different percentages of waste polyethylene to enhance durability and performance. The laboratory methodology consists of mix design and performance evaluation. The mix design follows ASTM D7064, NCHRP guidelines, and MS-2 recommendations to determine the optimal binder content. The modified binder is first evaluated for its rheological properties to ensure compatibility with the asphalt mix. After preparing the pervious asphalt specimens, various laboratory tests are conducted to assess their mechanical and functional properties, including permeability, stability, and moisture resistance. The results from these tests guide the optimization of the mix for improved performance in pervious pavement applications.

3.2 METHODOLOGY

This study utilizes a systematic method to assess the performance of waste polyethylene-modified pervious asphalt pavement. This process comprises material selection, mix design, specimen preparation, and laboratory testing to assess the mechanical and functional properties of the modified asphalt. The methodology aims to guarantee reproducibility and precisely assess how waste polyethylene affects binder modification and mix behavior. Standardized testing

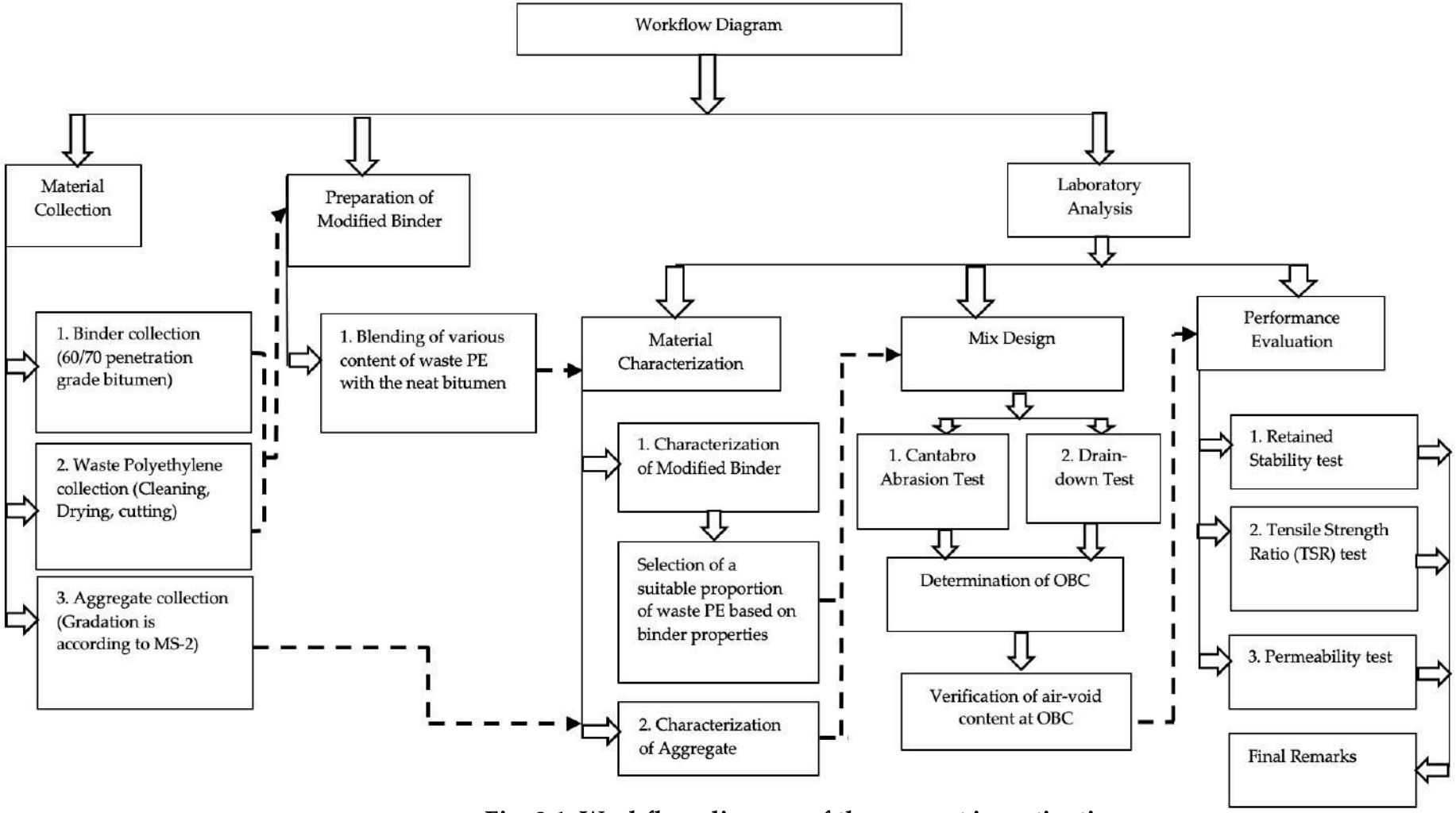


Fig. 3.1: Workflow diagram of the present investigation

protocols were employed to ensure consistency, and a comparative analysis was conducted with traditional asphalt mixes to demonstrate the effectiveness of the modification. The workflow diagram shown in Fig. 3.1 delineates the essential steps involved in the research.

3.3 MATERIAL COLLECTION

The materials required for this study were gathered from various sources to ensure quality and suitability for pervious asphalt pavement construction. Aggregates, comprising coarse and fine fractions, were sourced from local suppliers to satisfy the gradation requirements. Waste polyethylene, utilized as a modifier, was derived from post-consumer polyethylene waste and processed into suitable sizes for blending with bitumen. The bitumen, acting as the primary binder, was obtained from a verified supplier, ensuring it met the necessary specifications.

3.3.1 Pervious Pavement Gradation

The gradation of aggregates plays a crucial role in the effectiveness of pervious asphalt pavement. Choosing the right aggregate gradation adheres to established standards, including guidelines from the National Cooperative Highway Research Program (NCHRP) and the MS-2 Asphalt Mix Design Manual. Table 3.1 presents the recommended gradation ranges for pervious asphalt pavement from MS-2. In this investigation NCHRP 640 1/2" gradation range is selected. The selected gradation for ensuring the required void content is shown in Fig. 3.2.

Table 3.1: Gradation specifications of open-graded surface mixes

Sieve Size	NCHRP 640 1/2"	NCHRP 640 3/8"	Oregon 1/2"	Georgia 1/2" PEM
¾" (19 mm)	100	—	99–100	100
½" (12.5 mm)	80–100	100	90–98	80–100
⅜" (9.5 mm)	35–60	85–100	—	35–60
No. 4 (4.75 mm)	10–25	20–30	18–32	10–25
No. 8 (2.36 mm)	5–10	5–15	3–15	5–10
No. 16 (1.18 mm)	—	—	—	—
No. 30 (0.60 mm)	—	—	—	—
No. 50 (0.30 mm)	—	—	—	—
No. 100 (0.15 mm)	—	—	—	—
No. 200 (0.075 mm)	0–4	0–4	1–5	1–4

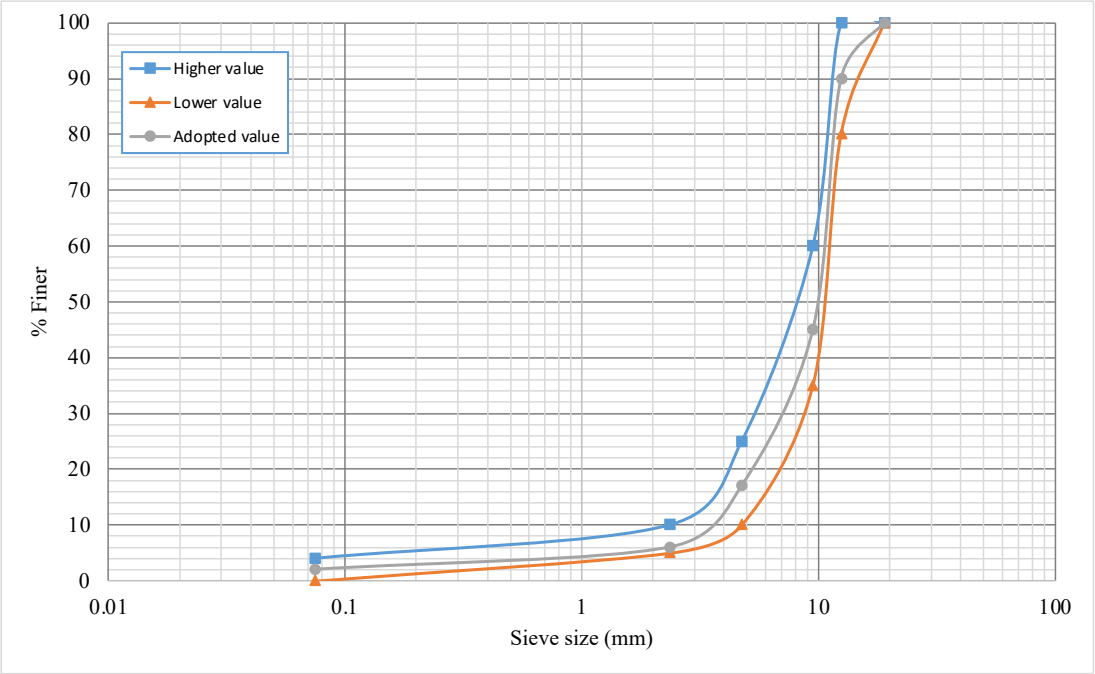


Fig. 3.2: Adopted aggregate gradation curve for pervious asphalt pavement (*MS-2, 7 th Edition Asphalt Mix Design Methods*, 2014)

3.3.1.1 Coarse Aggregate

The coarse aggregate utilized in this study consists of Sylhet stone chips sourced from the Sylhet region from a local vendor, which is renowned for its high strength and durability. To ascertain the appropriateness of these aggregates for pervious asphalt pavement, an evaluation of various mechanical properties is undertaken. Standardized tests are conducted in accordance with relevant specifications, including:

- The Los Angeles Abrasion Test (ASTM C131) assesses resistance to wear and degradation.
- Soundness Test (ASTM C88) to assesses resistance to degradation from weathering, especially freeze-thaw cycles.
- Aggregate Impact Value (AIV) Test (BS 812-112) for assessing toughness and impact resistance.
- Aggregate Crushing Value (ACV) Test (BS 812-110) for assessing static load resistance.
- Specific Gravity and Water Absorption Test (ASTM C127) to assess density and porosity.
- Flakiness and Elongation Index (BS 812-105.1) determine the shape characteristics of the aggregates.

These tests assist in selecting aggregates that ensure the necessary strength, permeability, and durability for waste polyethylene-modified pervious asphalt pavement.

3.3.1.2 Fine Aggregate

The fine aggregate utilized in this study assumes a pivotal role in filling the voids between coarse aggregates, thereby ensuring appropriate gradation and workability of the pervious asphalt mix. The fine aggregate is derived from natural river sand, recognized for its cleanliness and well-graded particle distribution. To ascertain its suitability for pervious pavement, several standard tests are conducted, including:

- Sieve analysis (ASTM C136) is used to determine particle size distribution.
- Specific gravity and water absorption test (ASTM C128) for evaluating density and absorption capacity.

These tests ensure that the fine aggregate contributes to the required permeability, stability, and durability of the waste polyethylene-modified pervious asphalt pavement.

3.3.2 Waste Polyethylene

In this study, the waste polyethylene was sourced from a recycling facility in Chattogram. It was shredded and cleaned before being utilized as a modifier for bitumen. The polyethylene was sorted, dry, and free of dust, which made it ideal for pavement use. The average particle size was 5 mm, ensuring it mixed uniformly with the bitumen. Collected waste polyethylene from the recycling facility is shown in Fig. 3.3. Most of the polyethylene collected was low-density polyethylene (LDPE), with a smaller amount of high-density polyethylene (HDPE). The use of waste polyethylene supports sustainable waste management by converting discarded polyethylene into useful materials.



Fig. 3.3 Waste polyethylene collected from a recycling facility

3.3.3 Binder

The base binder used in this study is 60/70 penetration grade bitumen, a commonly used asphalt binder recognized for its balanced viscosity, ductility, and resistance to temperature fluctuations. It offers excellent adhesion to aggregates, ensuring structural stability in pavement applications. To enhance the performance of pervious asphalt pavement, the binder is modified using waste polyethylene.

3.3.3.1 *Neat Bitumen*

This study utilizes 60/70 penetration grade bitumen as the base binder, which is widely recommended in Bangladesh for asphalt pavement applications. The specific bitumen employed in this study is produced at the Bashundhara Bitumen Plant. This bitumen grade provides adequate viscosity, good workability, and sufficient resistance to temperature fluctuations, making it an ideal option for road construction in Bangladesh. To ensure the quality and performance of the neat bitumen, standard laboratory tests such as penetration, softening point, viscosity, ductility, and flash & fire point tests are conducted following ASTM and AASHTO standards.

- Penetration Test (ASTM D5) – Measures the hardness or softness of bitumen by assessing the depth (in tenths of a millimeter) that a standard needle penetrates under specific conditions. A lower penetration value indicates a harder binder.
- Softening Point Test (ASTM D36) – Measures the temperature at which bitumen softens and turns fluid under controlled conditions. A higher softening point indicates better resistance to temperature-induced deformation.
- Viscosity Test (ASTM D4402) – Evaluates the flow characteristics of bitumen at varying temperatures to ensure sufficient workability and resistance to rutting.
- Ductility Test (ASTM D113) – Assesses the elasticity of bitumen by measuring its elongation before failure. A higher ductility value indicates improved flexibility and resistance to cracking.
- Loss on Heating Test (ASTM D6) – Determine the amount of volatile components that evaporate, which can affect the bitumen's hardness and brittleness.
- Flash and Fire Point Test (ASTM D92) – Determines the temperature at which bitumen emits vapors capable of igniting (flash point) and sustaining combustion (fire point), ensuring safe handling during construction.
- Specific Gravity Test (ASTM D70) – Measures the density of bitumen, which is essential for mix design calculations.
- Elastic Recovery Test (ASTM D6084)- Evaluate how well the polymers improve the material's elasticity. This assessment reveals the material's capacity to withstand permanent deformation and fatigue, which is essential for optimal pavement performance.

- Thin Film Oven Test (TFOT) (ASTM D1754) – Simulates short-term aging of bitumen by exposing it to heat and air and assesses changes in properties such as viscosity and penetration.
- Tests on Residue from TFOT:
    i. Softening Point Test on Residue (ASTM D36) - Assesses the impact of aging on temperature susceptibility.
    ii. Penetration Test on Residue (ASTM D5) - Determines the hardness of the bitumen after aging.

These tests create a performance baseline for neat bitumen and act as a reference to compare the improvements gained by using a binder modified with waste polyethylene.

3.3.3.2 *Bitumen Modified by Waste Polyethylene*

The wet process of modification is adopted for this study. The preparation of waste polyethylene-modified bitumen involves varying percentages of waste polyethylene being blended with neat bitumen under controlled conditions to achieve uniform dispersion. This study incorporated 3%, 4%, 5%, and 6% waste polyethylene by weight into 60/70 grade bitumen.

The modification process commenced by heating neat bitumen to the required temperature to ensure fluidity and ease of blending. The bitumen was then poured into a high-speed blender equipped with a shear blade, shown in Fig. 3.4.



Fig. 3.4: Blending waste polyethylene with neat bitumen in a high-speed blender in the laboratory

The waste polyethylene, in shredded form, was gradually added to the hot bitumen while mixing manually. After initial mixing, the blender was operated at a high blending speed. The high shear forces facilitated the thorough mixing of polyethylene with the bitumen, ensuring uniform dispersion. As the waste polyethylene used in this study was primarily low-density polyethylene (LDPE), a mixing duration of 30 minutes will be sufficient for complete dispersion (Hinislioglu and Agar, 2004). The blending process was carried out at an optimized temperature range of 160-170°C to prevent degradation of the polymer while ensuring proper uniformity modification. After mixing, the modified binder was allowed to cool and was subsequently subjected to standard bitumen tests to evaluate its viscosity, penetration, softening point, ductility, etc. These tests offered insights into how modifying waste polyethylene enhanced the binder properties when compared to neat bitumen, especially regarding rutting resistance, durability, and moisture susceptibility.

Table 3.2: Specifications Requirement for Modified Bitumen (IRC SP 53)

	Highest Mean Air Temperature	< 20°C	20°C to 35°C	Above 35°C		
	Lowest Mean Air Temp.	>-10 < -10	>-10 < -10	>-10		
Sl. No. (1)	Characteristics (2)	Specified values for the bitumen (3)	(4)	(5)	Method of Test. IS No. (6)	Ref to Annexure (7)
i)	Penetration at 25°C, 0.1 mm, 100g, 5 s	60 to 120	50 to 80	30 to 50	1203	-
ii)	Softening point, (R&B), °C, Min.	50	55	60 *	1205	-
iii)	FRAASS* breaking point, °C, Max	-20	-16	-12	9381	-
iv)	Flash Point, COC, °C, Min.	220	220	220	1209	-
v)	Elastic recovery of half thread in ductilometer at 25°C, percent, min.	50	60	60		2
vi)	Complex modulus (G*/sin δ) as Min 1.0 kPa at 10 rad/s, at a temperature, °C	58	70	76		1
vii)	Separation, difference in softening point (R&B), °C, Max.	3	3	3		3
viii)	Viscosity at 150°C, Poise	1-3	3-6	5-9	1206 (Part 2)	-
ix)	Thin film oven test and tests on residue:					
	a) Loss in mass, percent, Max.	1.0	1.0	1.0	9382	-
	b) Increase in softening point, °C, Max.	7	6	5	1205	-
	c) Reduction in penetration of residue, at 25°C, percent, Max.	35	35	35	1203	-
	d) Elastic recovery of half thread in ductilometer at 25°C, percent, Min.	35	50	50	-	4
	Or					
	Complex modulus as (G*/ sin δ as Min 2.2 kPa at 10 rad/s, at temperature °C	58	70	76	-	1

To identify the most effective waste polyethylene content, the performance of modified bitumen was assessed against the standard requirements specified in IRC SP 53. The selection process involved comparing the measured properties of 3%, 4%, 5%, and 6% waste polyethylene-modified binders with the benchmark values stated in IRC SP 53. Table 3.2, summarizing the required values, was used

to identify the most effective dosage that meets both performance and durability criteria.

3.4 BITUMINOUS MIX DESIGN

The bituminous mix design process for pervious asphalt pavement seeks to identify the optimum binder content that guarantees durability, permeability, and mechanical stability. The choice of binder content is based on various performance parameters, including air void content, resistance to draindown, and abrasion resistance. Guidelines from MS-2 and ASTM D7064 are followed to ensure a balanced mix design appropriate for pervious pavement applications. To determine the optimal binder content, void content analysis is performed to ensure adequate permeability, while the draindown test evaluates the risk of binder drainage during storage and transportation. Additionally, the Cantabro abrasion test assesses the durability of the mix under traffic and environmental conditions. By considering these key parameters, the most effective binder content is chosen for enhanced performance and longevity of pervious asphalt pavement. Three controlling factors of the mix design are briefly described below:

3.4.1 Cantabro Abrasion Test (ASTM D7064)

The Cantabro Abrasion Test is used to evaluate the durability of pervious asphalt mixtures by measuring their resistance to particle loss. Due to the high air void content of pervious pavements, they are more susceptible to raveling and degradation over time. In this test, compacted asphalt specimens are placed in a Los Angeles (LA) abrasion machine without steel balls and subjected to rotation at a speed of 30–33 rpm for 300 revolutions. The weight of the specimen before and after the test is recorded to determine the percentage of mass loss, which

indicates the material's resistance to abrasion. The result of the test is determined using the following equation:

$$P = [(P1-P2)/P1] \times 100 \quad (3.1)$$

Where:

P = Cantabro abrasion loss,

$P1$ = initial weight of the sample, and

$P2$ = final weight of the sample

A smaller percentage of weight loss indicates greater durability, allowing the pavement to endure traffic and environmental pressures. In the case of pervious asphalt pavements, the maximum Cantabro loss permitted is 15% (*MS-2 7 th Edition Asphalt Mix Design Methods*, 2014). Should the test results surpass this threshold, modifications to the binder content or aggregate gradation might be necessary to enhance durability. This test is crucial for determining the ideal mix that achieves a balance of strength, permeability, and longevity in pervious pavement applications.

3.4.2 Drain-down Test (ASTM D6390)

The Drain-down Test represents an essential assessment within the mix design process of pervious asphalt pavement. This evaluation measures the potential loss of binder from the uncompacted asphalt mixture at elevated temperatures. Given the high air void content characteristic of pervious asphalt, there exists a considerable risk of binder separation, which may result in diminished durability and inconsistent performance of the mix.

In this test, the mix is placed in a wire mesh basket and heated in an oven at the paving temperature (typically between 150–175°C) for 1 hour. After the heating period, any binder or fine aggregates that have drained out of the mix are collected in a pre-weighed tray. The percentage of drain-down is then calculated by comparing the weight of the collected material to the initial sample weight. According to ASTM D6390, the acceptable drain-down limit for pervious asphalt mixtures is typically less than 0.3%. If the drain-down exceeds this limit, adjustments may be needed in the binder content, polymer modification, or the use of fiber additives to enhance the mix's stability and prevent binder loss during production and application. The test result is determined using the following equation:

$$\text{Draindown (percent)} = (D-C)/(B-A) \times 100 \quad (3.2)$$

Where:

A = mass of the empty wire basket,

B = mass of the wire basket and sample,

C = mass of the empty catch plate or container, and

D = mass of the catch plate or container plus drained material.

3.4.3 Design Optimum Binder Content (OBC) Determination

Determining the Optimum Binder Content (OBC) is crucial for designing a pervious asphalt mixture that achieves a balance between structural stability and functional permeability. In this study, we established the OBC using various performance tests, specifically the Cantabro Abrasion Test and the Drain-down Test.

A graph illustrates binder content in relation to abrasion loss and draindown potential, helping to pinpoint the acceptable range visually. According to MS-2 (Asphalt Institute Manual Series No. 2), the maximum allowable draindown is 0.3%, establishing the binder content's upper limit. Surpassing this threshold signifies excessive binder separation, potentially compromising the mix's structural integrity. On the other hand, the Cantabro Abrasion Test defines the binder content's lower limit, allowing for a maximum abrasion loss of 15% to maintain adequate resistance to raveling and surface deterioration. A typical graph depicting the philosophy of designing of pervious asphalt pavement is shown in Fig. 3.5.

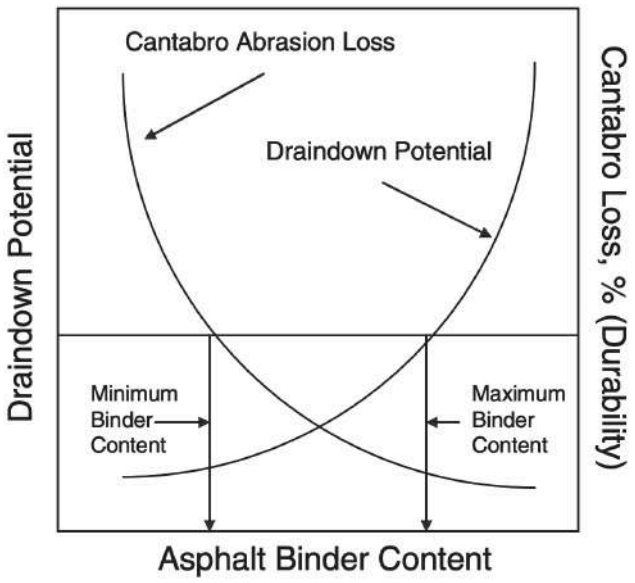


Fig. 3.5: Philosophy of designing pervious asphalt mixes (*NCHRP Report 640*, n.d.)

Despite these performance limits, they are inadequate for pervious pavements. Given that permeability is a fundamental characteristic, it is crucial for the mixture to maintain a sufficiently high void structure. Accordingly, the chosen range of binder content was further validated through testing of air void content. Only those binder contents that produced an air void content between 18% and 22% were deemed acceptable, thereby ensuring enough interconnected

voids to facilitate water infiltration. By satisfying the three criteria—Cantabro abrasion loss, drain-down limit, and air void content—a reliable range of binder content was chosen for durable, permeable asphalt pavements using waste polyethylene-modified binders.

3.4.4 Air Void Content Test (AASHTO T331)

The air void content constitutes a critical parameter in the mix design of pervious asphalt pavement, significantly influencing both permeability and structural integrity. The AASHTO T331 serves as the reference standard for determining the percentage of air voids present in the compacted asphalt mixture. In the context of pervious pavement, the requisite air void content typically ranges from 18% to 22%, thereby ensuring adequate porosity for water infiltration while concurrently sustaining mechanical stability (*MS-2 7 th Edition Asphalt Mix Design Methods*, 2014). Adhering to this prescribed range for air voids facilitates the attainment of the dual objectives of effective drainage and durability in applications involving pervious pavement. To determine the air void, bulk specific gravity and theoretical maximum specific gravity are needed. Theoretical maximum specific gravity is determined using the following equation:

$$G_{mm} = \frac{W_{mix}}{\frac{W_{CA}}{G_{CA}} + \frac{W_{FA}}{G_{FA}} + \frac{W_F}{G_F} + \frac{W_B}{G_B}} \tag{3.3}$$

Where,

G_{mm} = Theoretical maximum specific gravity of the mixture

W_{mix} = Total weight of the bituminous mixture

W_{CA} = Weight of coarse aggregate

W_{FA} = Weight of fine aggregate

W_F = Weight of filler

W_B = Weight of bitumen

G_{CA} = Specific gravity of coarse aggregate

G_{FA} = Specific gravity of fine aggregate

G_F = Specific gravity of filler

G_B = Specific gravity of bitumen

The following formula may be used to get the bulk specific gravity, also known as the actual specific gravity of the mixture, G_m, which takes air voids into account (ASTM D2726).

$$G_{mb} = \frac{W_{dry}}{W_{SSD} - W_{submerged}} \tag{3.4}$$

Where,

G_{mb} = Bulk specific gravity of the bituminous mix

W_{dry} = Weight of the dry specimen in air

W_{SSD} = Weight of the specimen in saturated surface-dry condition, and

$W_{submerged}$ = Weight of the specimen in water

The air voids (V_a) in a bituminous mix are calculated using the following formula:

$$V_a = \left(\frac{G_{mm} - G_{mb}}{G_{mm}} \right) \times 100 \tag{3.5}$$

Where,

V_a = Air voids in the mix (%)

G_{mm} = Theoretical maximum specific gravity of the mix (no air voids)

G_{mb} = Bulk specific gravity of the bituminous mix

3.5 PERFORMANCE EVALUATION

The performance evaluation of waste polyethylene-modified pervious asphalt pavement assesses its durability, moisture resistance, and permeability under various conditions. Several tests, such as the Retained Stability Test, Tensile Strength Ratio (TSR) Test, and Permeability Test, are performed following established reference standards. These tests help determine the mix's resistance to moisture damage, its capacity to retain strength after conditioning, and its effectiveness in allowing water infiltration through the pavement surface. The results from these tests offer valuable insights into the long-term performance and suitability of the modified pervious asphalt for real-world applications. The pavement performance evaluation tests are briefly described below.

3.5.1 Retained Stability Test (ASTM D1075)

The Retained Stability Test plays a key role in assessing the performance of waste polyethylene-modified pervious asphalt. This test assesses the ability of the asphalt mixture to maintain stability and resist damage caused by moisture after conditioning. According to ASTM D1075, the procedure involves preparing specimens of the modified asphalt mix, subjecting them to moisture conditioning at 60°C for 24 hours, and then measuring their stability and flow.

Retained stability is calculated by taking the ratio of the stability of the conditioned specimen to that of the original specimen. The result of the test is determined using the following equation:

$$\text{Retained stability, \%} = (S_2/S_1) \times 100 \quad (3.6)$$

Where,

S_1 = stability of unconditioned specimen, and

S_2 = stability of conditioned specimen.

A high retained stability suggests better moisture resistance and enhanced durability, making this test vital for assessing the long-term performance of the modified pavement under real-world conditions.

3.5.2 Tensile Strength Ratio (TSR) Test (ASTM D4867)

The Tensile Strength Ratio (TSR) test is a critical performance evaluation method used to assess the moisture susceptibility of asphalt mixtures, particularly those containing modified binders. This test is performed in accordance with the ASTM D4867 standard and assists in determining the influence of moisture on the tensile strength of the bituminous mixture. The TSR compares the indirect tensile strength of moisture-conditioned asphalt to that of dry mixture. To execute the TSR test, samples of the bituminous mixture are initially subjected to a conditioning process, wherein they are immersed in water at a specified temperature for a designated duration, typically 24 hours. Subsequently, the indirect tensile strength is measured for both the dry and moisture-conditioned specimens utilizing an appropriate testing machine. A schematic diagram of indirect tensile strength test setup is shown in Fig. 3.6.

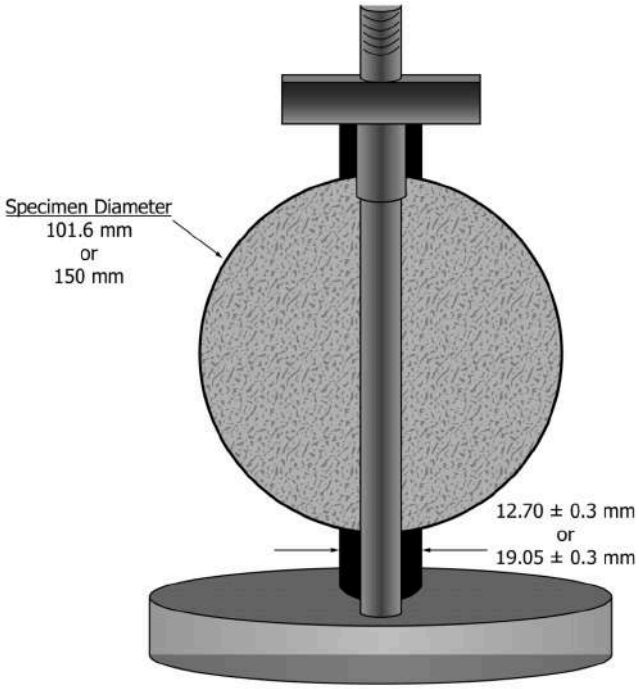


Fig. 3.6: Diagram of an Indirect Tensile Strength-Loading Fixture

Calculation of indirect tensile strength is as follows:

$$S_t = 2000\ P / \pi t D \tag{3.7}$$

Where,

S_t = tensile strength, kPa

P = maximum load, N

t = specimen height immediately before tensile test, mm

D = specimen diameter, mm

The TSR is calculated using the formulated equation:

$$TSR = (S_{tm}/S_{td}) \times 100 \tag{3.8}$$

Where,

TSR = tensile strength ratio, %

S_{tm} = average tensile strength of the moisture-conditioned subset, kPa (psi),

S_{td} = average tensile strength of the dry subset, kPa (psi).

A TSR value exceeding 80% is generally considered satisfactory, indicating that the asphalt mixture exhibits resistance to moisture-related damage. In contrast, a TSR value below this level suggests the potential susceptibility of the mixture to stripping or reduced durability in wet conditions. The TSR test is crucial in ensuring the long-term performance and reliability of pervious pavement, especially in areas with high rainfall or humidity.

3.5.3 Permeability Test

The permeability test is a key performance evaluation method for pervious asphalt pavements, as it assesses the mix's ability to allow water infiltration. Pervious pavements are specifically designed to manage stormwater by facilitating infiltration, reducing runoff, and promoting groundwater recharge. Establishing an optimal permeability rate is essential for the pavement's functionality and durability. It indicates the amount of fluid passing through a specific unit area per unit time under a unit hydraulic gradient (El-Hassan and Kianmehr, 2018). Generally, in hydraulics, to calculate the coefficient of permeability (k), Darcy's law is used (Das, and Sawicki, 2001).

The equation is as follows:

$$k = (aL) / (At) \times ln(h_1 / h_2) \quad (3.9)$$

where,

k = coefficient of permeability, mm/s

a = cross-sectional area of the standpipe, mm^2

L = length of the sample, mm

A = cross-sectional area of the specimen, mm^2

t = time interval, s

h_1 = initial head of the water, mm, and

h_2 = final head of the water, mm

A modified falling-head permeability test can assess the coefficient of permeability (Rao et al., 2022). Fig. 3.7 shows a schematic diagram of the test setup used to determine the infiltration rate of pervious asphalt mixes.

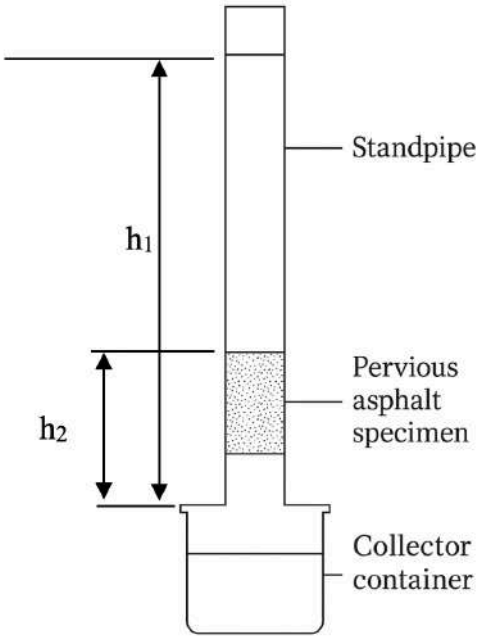


Fig. 3.7: Schematic diagram of falling-head permeability test setup

The pervious asphalt specimens are inserted into the same diameter standpipe. To prevent the water leakage, the edges of the specimen are sealed off with asphalt. By allowing water to flow through, the specimens became thoroughly saturated, creating an elevation effect when they reached the top. Then permeability test was done using different head elevation. The draining time is recorded to find out the coefficient of permeability.

3.6 SUMMARY

This chapter discusses the materials utilized, the techniques for preparation, and the testing methods implemented to assess the bituminous mixtures and binder modifications. From the results of the experimental investigation, we can draw the following conclusions:

1. The essential properties of neat bitumen, modified binders, aggregates, and waste polyethylene must be characterized to ascertain their compliance with the specifications required for pavement construction.
2. Among the various concentrations investigated, a specific optimal percentage of waste polyethylene has to be determined, fulfilling the binder property requirements in accordance with pertinent standards.
3. The optimal binder content has to be determined through a thorough analysis of Cantabro abrasion, drain-down test, and air void content test results. This evaluation aimed to ensure the mix's durability, resistance to binder drainage, and appropriate permeability.
4. Multiple tests, such as retained stability, tensile strength ratio (TSR), and permeability, have to be conducted to evaluate the functional and mechanical properties of the bituminous material mixtures.

5. The study will investigate pervious asphalt as a sustainable alternative to conventional pavements for improving surface drainage and reducing runoff in urban areas.

Chapter 4: EXPERIMENTAL INVESTIGATION AND DISCUSSION

4.1 GENERAL

This chapter outlines the experimental results and discussions resulting from the lab evaluation of waste polyethylene-modified pervious asphalt pavement. A range of tests was performed to evaluate the performance of both binder and mix, employing standard methods to guarantee accuracy and reliability. The study starts with the characterization of both neat and modified binders, analyzing their physical and rheological properties to comprehend how waste polyethylene affects binder behavior. Subsequently, attention is directed towards the pervious asphalt mix, in which the optimum binder content was determined based on essential mix design criteria, including air void content, Cantabro abrasion loss, and drain-down potential. The performance evaluation of the prepared mixes was then conducted through tests such as retained stability, tensile strength ratio (TSR), and permeability, which offered insights into durability, moisture sensitivity, and functional performance. This chapter aims to offer a thorough examination of the material properties and functional performance of the proposed pervious pavement system, thereby supporting its prospective application within the realm of sustainable pavement engineering. All parameters have been tested at least three times for averaging and repeatability, and the results that appear abnormal have been discarded.

4.2 MATERIAL CHARACTERIZATION

This section presents the test results of the materials used in this study, including aggregates, neat bitumen, and waste polyethylene. These findings were used to assess the materials' suitability and guide the mix design and performance evaluation. The characterization results further contribute to comprehending how waste polyethylene influences the properties of the modified binder and behavior of the various bituminous mixes.

4.2.1 Aggregate Properties

The physical and mechanical properties of both coarse and fine aggregates utilized in this study were thoroughly evaluated to ascertain their suitability for pervious asphalt pavement. These assessments are essential for evaluating the strength, durability, and compatibility of the aggregates within the mixture.

4.2.1.1 *Coarse Aggregate*

Coarse aggregates play a vital role in the structural strength and permeability of pervious asphalt pavement. This study used crushed Sylhet stone chips, widely available and commonly used in road construction in Bangladesh, as coarse aggregates. To ensure their suitability, various physical and mechanical properties were tested according to standard procedures mentioned in article 3.3.1.1. The detailed results are shown in Table 4.1.

4.2.1.2 *Fine Aggregate*

The fine aggregate used in this study was natural river sand sourced from local areas near the Chattogram region. This type of sand is commonly utilized in asphalt mixtures due to its clean, well-graded quality and appropriate fineness. Several standard tests mentioned in article 3.3.1.2 were performed to

evaluate the quality and suitability of the fine aggregate. Table 4.1 presents a summary of the test results.

Table 4.1: Physical Properties of Aggregates

Test	Coarse Aggregates		Fine Aggregates	
	Obtained	Standard MS-2, RHD	Obtained	Standard MS-2, RHD
1. Bulk Specific Gravity	2.78	---	2.66	---
2. Water Absorption (%)	1.72	---	2.02	---
3. Soundness (5 Cycles) in $MgSO_4$ (%)	3	≤15	3	≤15
4. Los Angeles Abrasion Value (%)	18	≤30	---	---
5. Aggregate Impact Value (%)	12	≤20	---	---
6. Aggregate Crushing Value (%)	18	≤25	---	---
7. Fractured Faces (1ff) (%)	100	100	---	---
8. Flakiness Index	12	≤30	---	---
9. Elongation Index	7	≤45	---	---

4.2.2 Waste Polyethylene

In this study, waste polyethylene utilized as a modifier for bitumen was evaluated to assess its potential for enhancing the performance of pervious asphalt pavement. The material was obtained in a pre-processed form—cleaned, shredded, and dried—from a recycling facility in Chattogram. Before incorporating it into the binder, a visual inspection and size consistency check were conducted to confirm its suitability. Most of the polyethylene was identified as LDPE, which is preferred for its lower melting point and superior blending characteristics with bitumen. A uniform particle size of approximately 5 mm was maintained for proper dispersion during the modification process. The influence of polyethylene on binder performance was subsequently analyzed in terms of

physical properties such as penetration, softening point, and ductility to determine its compatibility and effectiveness.

4.2.3 Modified Binder Preparation

In this phase of the study, waste polyethylene was incorporated into 60/70 grade neat bitumen to create polymer-modified binders. The primary objective was to enhance the performance characteristics of conventional bitumen using a sustainable and low-cost modifier. Waste polyethylene was added in four different concentrations—3%, 4%, 5%, and 6% by weight of bitumen—to observe the effect of varying polymer content on the physical and mechanical properties of the modified binder. The blending process utilized a custom-fabricated high-shear mixing machine, designed specifically for the uniform and stable dispersion of polymers into bitumen. This machine featured a shear blade to enhance the cutting and mixing of the polymer granules within the bitumen matrix. For each batch, approximately 3000 grams of neat bitumen were introduced into the blending chamber, followed by the predetermined percentage of shredded waste polyethylene.

Mixing occurred at a consistent temperature of 170°C, which effectively softens and partially melts LDPE without causing degradation. The blending process was conducted at a rotational speed of 1600 rpm, with a total blending time of 30 minutes to ensure thorough interaction between the binder and the polyethylene particles. This moderate speed and controlled temperature allowed the LDPE to be uniformly distributed in the bitumen without overheating or clumping, which is crucial for achieving a homogeneous and stable binder. The significance of uniform dispersion cannot be overstated, as insufficient mixing may result in the segregation of the polymer, phase separation, or inconsistent binder properties across various samples. Following the mixing process, the

waste polyethylene-modified binders were permitted to cool at ambient temperature and were subsequently stored for subsequent laboratory evaluation. The binders underwent a series of standard physical tests—such as penetration, softening point, ductility, and viscosity—to evaluate the impact of polyethylene on the binder's consistency, elasticity, and temperature susceptibility. These results were then compared with those of the neat binder to ascertain the most appropriate polymer content for applications in pervious asphalt pavement.

4.2.4 Neat Bitumen and Modified Binder Properties

This section presents the physical properties of both the neat 60/70 grade bitumen and the modified binders prepared using waste polyethylene at varying concentrations (3%, 4%, 5%, and 6% by weight of bitumen). The binders underwent a series of standardized tests, including penetration, softening point, ductility, viscosity, and thin film oven test (TFOT) properties, to evaluate their performance characteristics. The results of the physical and mechanical properties of neat bitumen and modified bitumen have been presented in Table 4.2.

Upon careful consideration of the results derived from all evaluated binder properties, as presented in Table 4.2, it is apparent that a concentration of 4% waste polyethylene yields the most balanced performance outcomes. Among the four modified binders, the incorporation of 4% waste polyethylene has resulted in an optimal combination characterized by an enhanced softening point, lower penetration, acceptable elastic recovery, and improved viscosity. These attributes signify elevated stiffness and thermal stability while maintaining appropriate workability and flexibility. The choice of this concentration is consistent with the benchmark criteria delineated in the IRC SP:53 code, which specifies the desired performance characteristics for polymer-modified bitumen utilized in road

construction projects. As previously referenced in Article 3.3.3.2, this guideline served as the foundational framework for assessing the suitability of each formulation. Consequently, the 4% waste polyethylene-modified binder has been identified as the most suitable candidate for the subsequent phases of mix design and performance evaluation in this study.

Table 4.2: Physical Properties of Neat and Modified Binders

Test		Standard	Neat Bitumen	3% waste PE	4% waste PE	5% waste PE	6% waste PE	Standard Value for PMB, IRC SP:53
Penetration, (0.1mm)		ASTM D5	67	43	40	35	34	30-50
Softening Point, °C		ASTM D36	47	58	64	66	68	≥60
Ductility, cm		ASTM D113	107	26	23	16	12	---
Loss on heating for 5 hrs. at 163°C		ASTM D6	0.16	0.0	0.0	0.0	0.0	---
Flash Point, °C		ASTM D92	315	322	330	336	340	≥220
Stripping of Bitumen-Aggregate Mix, Coated Area %		ASTM D1664	>95	>95	>95	>95	>95	>95
Elastic Recovery of half thread at 25°C, %		ASTM D6084	27	65	61	52	40	≥60
Viscosity at 150°C, poise		ASTM D4402	2.1	5.1	6.5	13.8	21.2	5-9
Thin Film Oven Test & Test on Residue	Loss in mass, %	ASTM D1754	1.63	1.23	0.91	0.83	0.64	≤1.0
	Increase in Softening Point, °C	ASTM D36	4	3	5	6	7	≤5
	Reduction in penetration, %	ASTM D5	24	28	32	35	38	≤35

4.2.5 Temperature Susceptibility of Binders

Following the selection of the optimal waste concentration for bitumen modification, an additional temperature susceptibility test was carried out to analyze how the modified binder performs at different temperatures. The objective was to evaluate the consistency and stability of both neat and modified binders when faced with temperature variations, a crucial factor for ensuring pavement durability in tropical climates such as Bangladesh.

Penetration tests were conducted at four distinct temperatures: 5°C, 15°C, 25°C, and 35°C. The outcomes of these tests are presented in Table 4.3. For neat bitumen, penetration values increased significantly with temperature, from 6 dmm at 5°C to 152 dmm at 35°C, indicating a high degree of temperature susceptibility. In contrast, the modified binder exhibited more stable behavior, with penetration values ranging from 11 dmm at 5°C to 49 dmm at 35°C, demonstrating better resistance to temperature fluctuations due to the addition of waste polyethylene.

Table 4.3: Penetration Values of Neat and Modified Binder at Different Temperatures

Temperature (°C)	Neat Bitumen (dmm)	Modified Binder (dmm)
5	6	11
15	23	12
25	67	40
35	152	49

To enhance the visualization of temperature response differences, a graph was created with temperature on the x-axis and penetration on the y-axis. Fig. 4.1 demonstrates the penetration trends for both binder types. A best-fit line has been

added to each dataset to depict the rate of change in penetration relative to temperature.

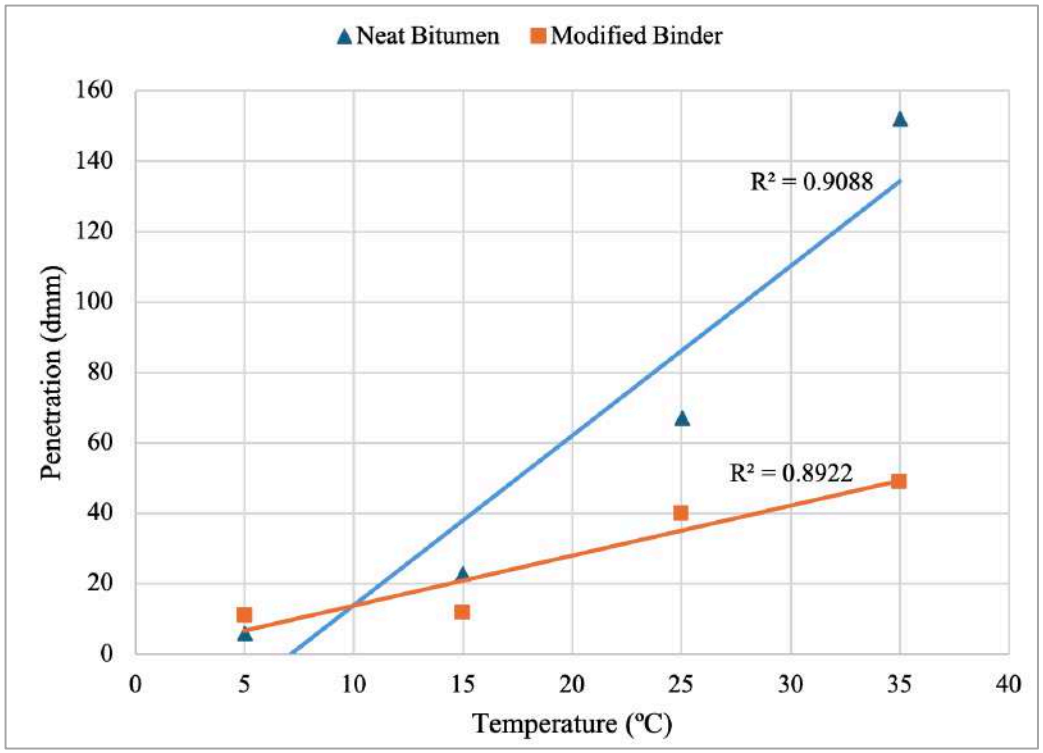


Fig. 4.1: Temperature Susceptibility of Various Binders

The slope of the neat bitumen trendline was distinctly steeper compared to that of the modified binder, indicating that the unmodified binder exhibits a greater sensitivity to temperature variations. In contrast, the gently inclined slope of the modified binder curve suggests that incorporating waste polyethylene substantially mitigates temperature susceptibility. This enhancement can be attributed to the polymer's capacity to improve the elasticity and structural integrity of the binder across a wide temperature spectrum.

This performance benefits areas like Bangladesh, where pavement surfaces are exposed to seasonal temperature fluctuations and prolonged monsoon seasons. The modified binder's enhanced thermal stability increases the

pavement's resistance to softening in heat and brittleness in cold, offering a longer service life and better performance under environmental stress.

4.3 BITUMINOUS MIX DESIGN

This section outlines the findings of the bituminous mix design focused on establishing the optimum binder content (OBC) for pervious asphalt pavement utilizing waste polyethylene-modified binders. Standard procedures were followed in performing various tests, including air void analysis, Cantabro abrasion, and drain-down tests, to determine the binder content that guarantees sufficient strength, durability, and permeability of the mix.

4.3.1 Design Method

This study's mix design for the pervious asphalt pavement was conducted according to the guidelines outlined in the NCHRP Report 640 and the MS-2 Manual of the Asphalt Institute. These references are widely acknowledged for their systematic approach to designing open-graded and porous asphalt mixtures, which aligns well with the objectives of this study.

The NCHRP Report 640 presents comprehensive procedures for assessing essential mix parameters like air void content, permeability, and durability, which are crucial for designing pervious pavements. Meanwhile, the MS-2 Manual offers practical guidelines for choosing suitable aggregate gradation and binder content to achieve a balance of structural integrity and water infiltration capacity.

Collectively, these references provide a comprehensive framework for designing a pervious mix that satisfies both mechanical and hydrological performance requirements, making them ideal for developing a polyethylene-modified pervious asphalt pavement within the scope of this study.

4.3.1.1 *Cantabro Abrasion Test*

The Cantabro Abrasion Test evaluates the durability of pervious asphalt mixtures, particularly their resistance to raveling and disintegration due to traffic-induced wear. Given that pervious pavements possess a high percentage of air voids, it is crucial to ensure sufficient aggregate cohesion for maintaining structural integrity. The Cantabro Abrasion test specimens before and after testing in the Los Angeles abrasion machine are shown in Fig. 4.2. According to the guidelines mentioned in MS-2, the maximum allowable particle loss should not exceed 15%. Calculation of Cantabro abrasion loss is done using equation 3.1. The test results for various binder contents are summarized in Table 4.4.



(a) (b)

Fig. 4.2: Cantabro abrasion test specimens (a) before test and (b) after test

Table 4.4: Cantabro Abrasion Loss and Drain-Down Values for Various Binder Contents

Binder Content (%)	Abrasion Loss (%)	Drain-down Potential (%)
5.0	17.37	0.01
5.5	12.97	0.41
6.0	9.69	2.10
6.5	8.12	2.52
7.0	6.67	3.31

The table clearly shows that abrasion loss decreases as binder content increases. Mixtures with a binder content of 5.5% and above satisfy the maximum allowable limit of 15%, indicating improved durability and cohesion at higher binder contents.

4.3.1.2 *Drain-down Test*

The drain-down test was conducted to assess the potential for binder separation in pervious asphalt mixes at elevated temperatures. Since these mixes contain a high percentage of interconnected voids and lack fine aggregates, the risk of binder drainage during transportation or placement is a concern, especially with higher binder contents. According to MS-2, the maximum allowable drain-down should not exceed 0.3%. The drain-down test setup in the laboratory is shown in Fig. 4.3. The draindown potential of the binder is calculated using equation 3.2. The results of the test for various binder contents are shown in Table 4.4.

The results clearly indicate that binder drain-down increases significantly with higher binder contents. These results indicate that the allowable maximum bitumen content lies between 5.0 % and 5.5 %. Higher bitumen content is

unsuitable for pervious asphalt mixes due to excessive drain-down, which can result in non-uniform binder distribution and reduced durability.

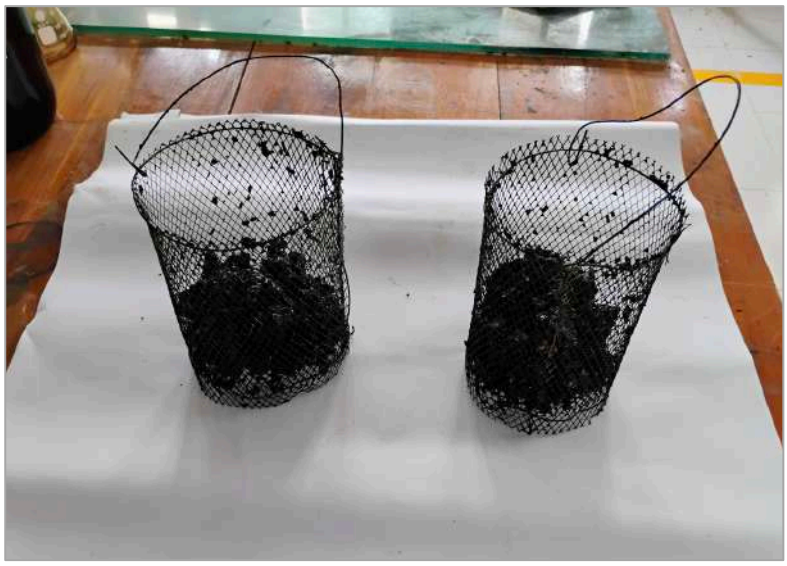


Fig. 4.3: Drain-down test is in progress

4.3.1.3 *Determination of Optimum Binder Content (OBC)*

The optimum binder content (OBC) for the pervious asphalt mix was determined by evaluating the results of the Cantabro abrasion test and drain-down test across various binder contents. The objective was to identify the range of binder contents that ensures sufficient durability while maintaining stability against binder drain-down.

The maximum allowable loss in the Cantabro abrasion test is 15%. From the data in Table 4.4 and the graph shown in Fig. 4.4, it is evident that the minimum binder content requirement is 5.25% of the weight of neat bitumen. On the other hand, the maximum allowable drain-down potential for the drain-down test is 0.3%. Based on the experimental data shown in Table 4.4 and illustrated in Fig. 4.4, the maximum allowable binder content is 5.4%.

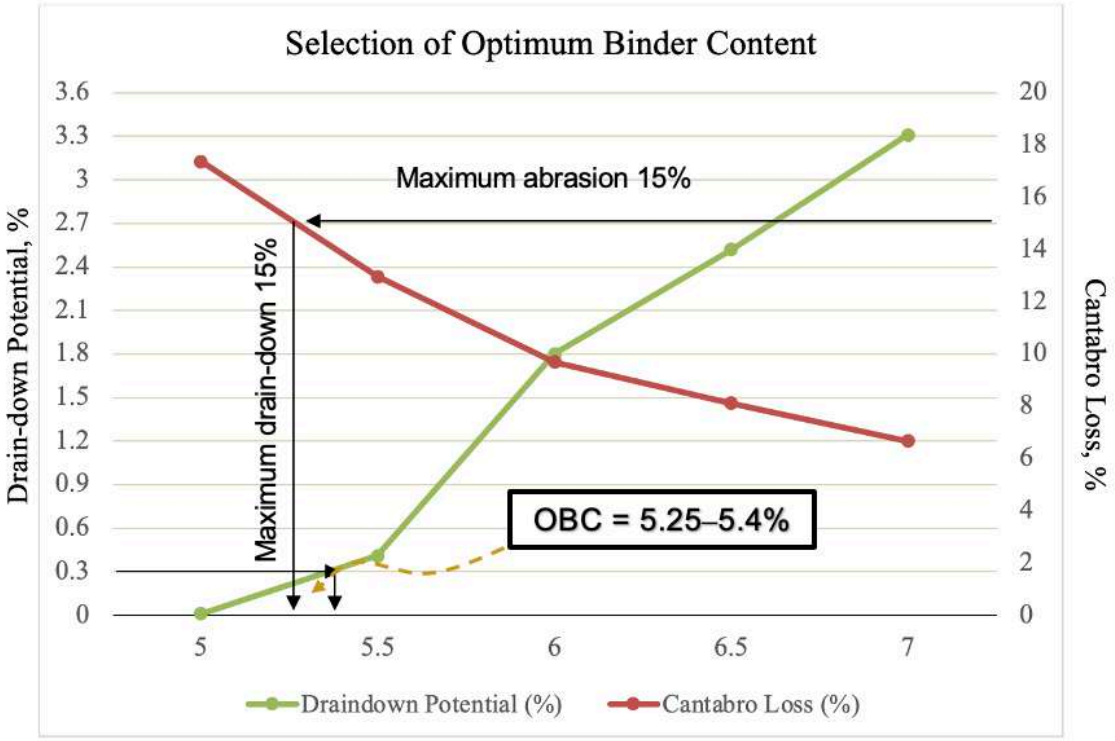


Fig. 4.4: Selection of OBC from Drain-down Potential and Cantabro Loss

Considering both criteria, the optimum binder content (OBC) lies between 5.25% and 5.4%, which satisfies both the abrasion resistance and drain-down stability requirements. This OBC range ensures a balanced performance in terms of mix durability and binder retention, making it suitable for pervious asphalt pavement applications. However, for preparing specimens for the next phase of performance testing, binder content at the higher end of this optimum range, 5.4% is selected. This decision was made to allow for the maximum incorporation of waste polyethylene while maintaining the integrity of the mix.

4.3.1.4 *Verification of Air Void Content at OBC*

Air void content is a crucial factor in the design of pervious asphalt mixes, impacting both permeability and strength. In this study, the air void test was conducted in accordance with AASHTO T331. MS-2 recommends a range of 18% to 22% to ensure proper drainage and maintain structural performance. Test

results from compacted samples were used to determine the optimum binder content based on this criterion. The results of the air void test are shown in Table 4.5.

Table 4.5: Air Void Content of Pervious Asphalt Mixes with Varying Binder Content (as per AASHTO T331)

Binder Content (%)	Air Void Content (%)
5.0	19.1
5.5	18.4
6.0	16.8
6.5	15.9
7.0	13.7

The experimental results indicate that the samples prepared with 5% and 5.5% bitumen content achieved air void levels within the acceptable range of 18–22%, as specified in MS-2 for pervious asphalt mixtures. This indicates that a binder content ranging from 5.25% to 5.4% is appropriate, as it provides sufficient voids to sustain the necessary permeability and structural stability for pervious pavement. Hence, it can be considered 5.4% as the optimum binder content.

4.4 PERFORMANCE TEST

To evaluate the functional efficiency and durability of the study, a series of performance tests were conducted to evaluate the functional efficiency and durability of the pervious asphalt mixtures. These tests were designed to assess the structural stability, moisture susceptibility, and drainage capability of the prepared mixes. The retained stability test was employed to examine the strength retention of the mixtures after conditioning, whereas the tensile strength ratio (TSR) test was utilized to evaluate the resistance of the mixture to moisture-

induced damage. Furthermore, the permeability test offered valuable insights into the mix's capacity for water infiltration, an essential characteristic of pervious pavement systems. The performance of specimens formulated with waste polyethylene-modified binders was compared against control specimens made with neat bitumen, enabling an assessment of enhancements in durability, stability, and permeability.

4.4.1 Retained Stability Analysis

Retained stability is a significant indicator of the moisture susceptibility of bituminous mixtures, reflecting the mix's ability to maintain structural integrity after exposure to moisture. In the present study, the retained stability of the asphalt mixes was assessed for both the control mix utilizing 60/70 grade neat bitumen and the polymer-modified mix formulated with the identified optimum binder content of 5.4%. The results demonstrate a considerable enhancement in performance with the incorporation of waste polyethylene into the binder. The test setup and the stability test being conducted in the laboratory are shown in Fig. 4.5.



Fig. 4.5: Retained stability test in progress

More notably, the comparison of absolute Marshall stability values before and after conditioning highlights the significant improvement associated with the modified binder. Fig. 4 .6 and Fig. 4 .7 show the stability of neat bitumen and modified bitumen. In the dry (unconditioned) subset, the stability of the polyethylene-modified mix was approximately 2.5 times greater than that of the control mix.

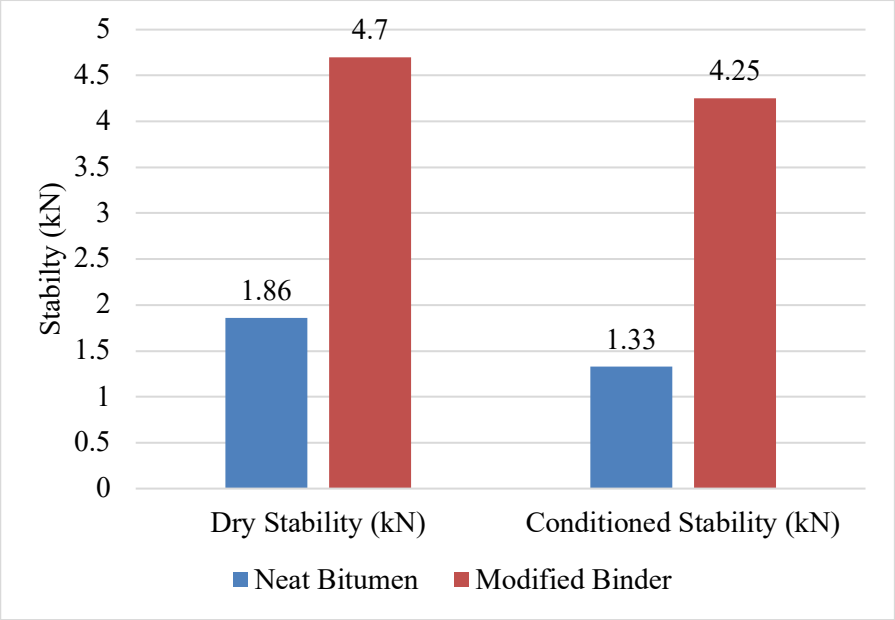


Fig. 4.6: Marshall stability comparison of neat bitumen and modified bitumen

Upon conditioning, this difference became even more pronounced, with the modified mix achieving a stability 3.2 times higher than the neat bitumen counterpart. This indicates that while both mixes experience a decline in stability due to moisture exposure, the reduction is considerably less severe for the modified binder, underscoring its enhanced resistance to moisture damage.

The retained stability values are shown in Fig. 4.7. The control mix, composed of neat bitumen, exhibited a stability retention of 71.5%, which is well below the generally accepted minimum threshold of 75% as per ASTM D1075 for

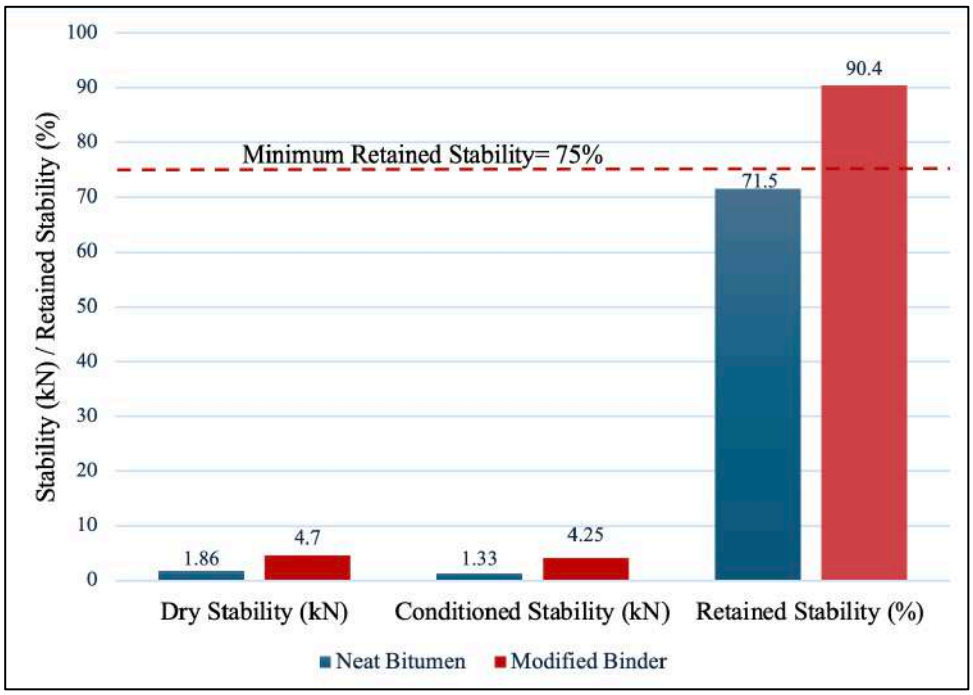


Fig. 4.7: Retained stability comparison of neat bitumen and modified bitumen

mixes prepared with modified bitumen. This suggests that the mix fails to meet the basic requirement; its resistance to moisture-induced degradation remains limited. In contrast, the mix with waste polyethylene-modified binder demonstrated a significantly higher stability retention of 90.4%, clearly indicating a superior ability to withstand moisture conditioning.

These findings substantiate the advantageous effect of integrating waste polyethylene into bituminous binders, contributing not only to the enhancement of initial stability but also to the preservation of structural performance in adverse environmental conditions.

4.4.2 Water Sensitivity Analysis

Moisture-induced damage is a significant concern in asphalt pavement design, particularly in pervious asphalt mixtures. The increased void content may lead to greater susceptibility to water infiltration and subsequent strength

loss. The Tensile Strength Ratio (TSR) test, as specified in ASTM D4867, was used to evaluate the moisture sensitivity of asphalt mixtures prepared with both neat 60/70 grade bitumen and waste polyethylene-modified binders. This test assesses the retained tensile strength of the mixture after conditioning under moisture, serving as a reliable indicator of the mix's resistance to stripping and water-related damage. The test setup and the indirect tensile strength test being conducted in the laboratory are shown in Fig. 4.8.



Fig. 4.8: Indirect tensile strength test in progress

The TSR is calculated using equation 3.8. The results obtained from the TSR test reveal a significant performance disparity between the two binder types. The variation in tensile strength and tensile strength ratio values for the two types of binders is illustrated in Fig. 4.9 and Fig. 4.10, respectively, which clearly demonstrates the superior performance of the polyethylene-modified binder under both conditioned and unconditioned states. For the control mixture prepared with neat bitumen, the average indirect tensile strength was 145.2 kPa for the unconditioned subset and 123.8 kPa for the moisture-conditioned subset. This yields a Tensile Strength Ratio of 85%, which, although within acceptable

limits, indicates a measurable reduction in tensile strength due to moisture exposure.

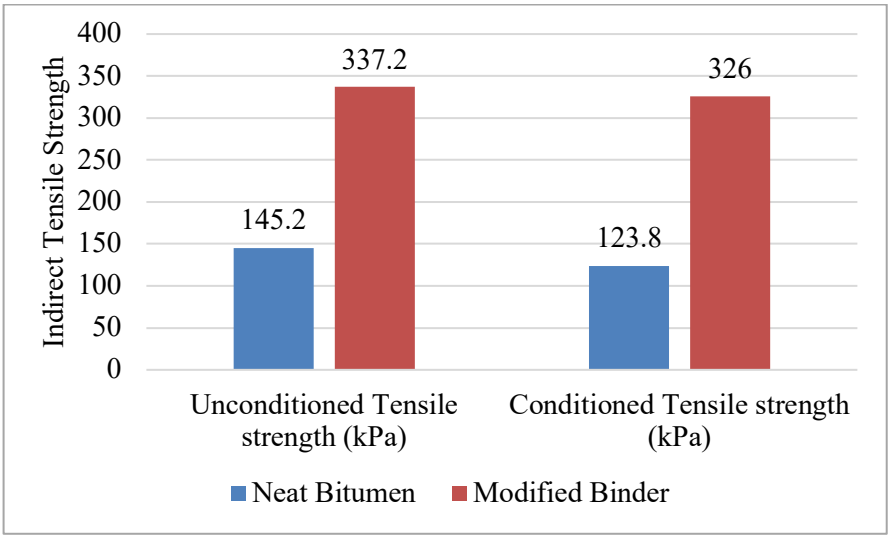


Fig. 4.9: Comparison of tensile strength between neat and modified binders

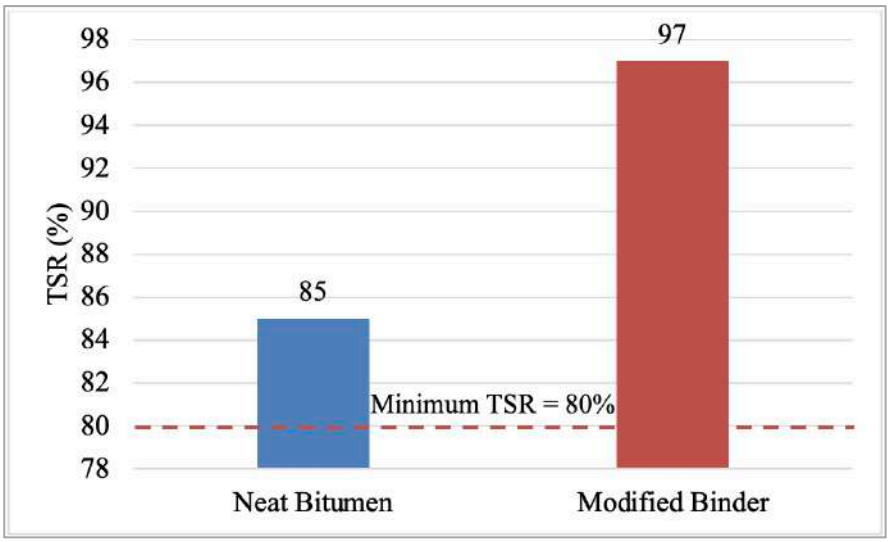


Fig 4.10: Comparison of tensile strength ratio between neat and modified binders

Conversely, the composite material comprising waste polyethylene-modified binder exhibited significantly enhanced resistance to moisture. The unconditioned samples displayed an average tensile strength of 337.2 kPa, while the conditioned samples maintained a strength of 326.0 kPa, resulting in a Tensile

Strength Ratio of 97%. This slight decrease in strength underscores the superior bonding and structural cohesion afforded by the waste polyethylene-modified binder, effectively mitigating the impact of moisture infiltration.

Significantly, the comparative analysis of the strength between the two binders further emphasizes the preeminence of the modified mixture. Under arid conditions, the indirect tensile strength of the modified mixture was approximately 2.3 times greater than that of the neat bitumen mixture. Under conditioned (wet) conditions, this ratio escalated to 2.6, illustrating the extraordinary retention of strength in the face of moisture exposure. These findings illuminate the enhanced cohesion and diminished stripping potential conferred by the polyethylene-modified binder.

4.4.3 Water Infiltration Rate

This sub-section delineates the water infiltration performance of pervious asphalt mixtures through the evaluation of the coefficient of permeability (k), which represents a critical parameter for determining the drainage efficiency of the pavement. The permeability values were ascertained utilizing the modified falling head permeability test, as outlined in Subsection 3.5.3, with calculations conducted in accordance with Equation 3.9, derived from Darcy's Law. To ensure reliable results, three replicate specimens were prepared for each binder type—one set using conventional 60/70 grade neat bitumen and another with waste polyethylene-modified binder. The test setup for determining water infiltration rate is shown in Fig. 4.11.

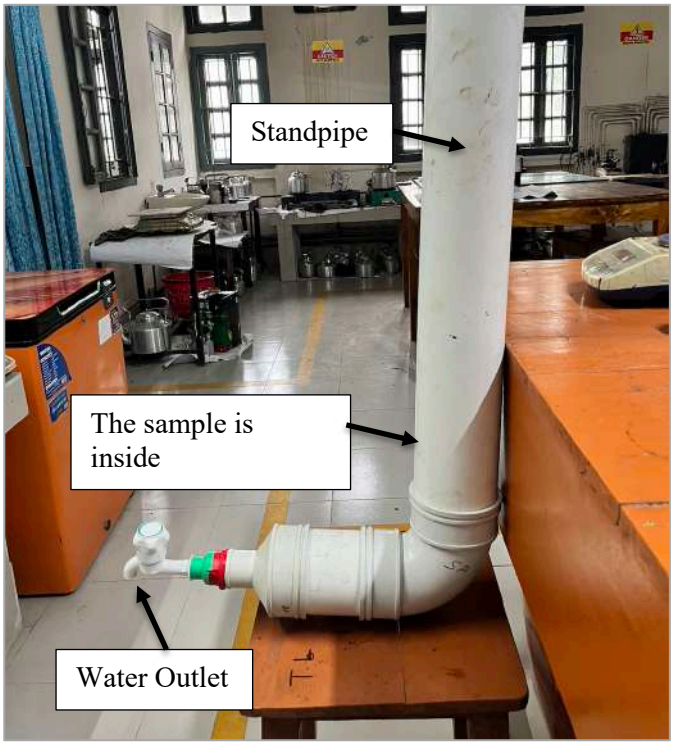


Fig. 4.11: Falling head permeability test setup in the laboratory

A comparative bar chart representing the k-values for both binder types, which supports the analysis presented in this section, is shown in Fig. 4.12. The average coefficient of permeability for the neat bitumen mix was found to be 3.0 mm/s, while the modified binder mix exhibited a significantly higher average value of 4.2 mm/s. Although the required k value is dependent on the usage, the minimum k value for pervious pavement is 1.0 mm/s (Akkaya and Çağatay, 2021).

The noticeable increase in permeability of the modified binder mix shows its effective capacity to enable water infiltration. The rise in the k-value indicates that adding waste polyethylene helps create a more interconnected and stable void structure in the asphalt mixture. This improved void network not only allows water to drain quickly but also supports the main goal of pervious pavement systems, which is to lessen surface runoff and reduce the chances of hydroplaning.

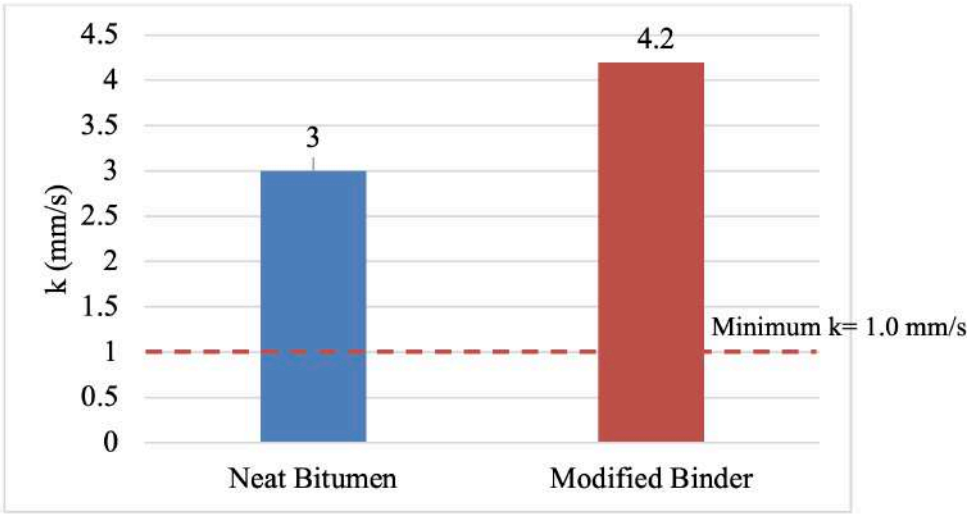


Fig. 4.12: Comparison of water infiltration rate between neat and modified bituminous mix

4.5 SUMMARY

This section outlines the key findings from the experimental investigations and performance evaluations of pervious asphalt mixtures created with a modified binder made from waste polyethylene. The results are discussed regarding the comparative performance of conventional neat bitumen versus the modified binder, with an emphasis on mechanical strength, moisture resistance, and permeability. The analysis leads to the following concluding points:

1. The mechanical properties of waste polyethylene-modified binder have been markedly improved in comparison to conventional binders. Additionally, its reduced temperature susceptibility suggests that this modified binder is suitable for use in both warm and cold regions.
2. According to the results from the Cantabro abrasion and drain-down tests, the ideal binder content was determined to be between 5.25% and 5.4%. This range achieved a balance between mechanical strength and mix stability. With this binder amount, the Cantabro loss stayed under 15%, and the drain-down remained below 0.3%, aligning with MS-2

standards. This optimal binder content range also meets the void content requirement of 18-22%.

3. The waste polyethylene-modified pervious mix showed improved Marshall stability at 4.25 kN, in contrast to 1.33 kN for the neat bitumen pervious mix under dry conditions. Moreover, the retained stability rose from 71.5% for the neat mix to 90.4% for the modified mix, indicating its enhanced resistance to moisture-related damage.
4. The Indirect Tensile Strength (IDT) for the modified pervious mix was 337.2 kPa in dry conditions and 326.0 kPa when conditioned. In contrast, the control pervious mix showed values of 145.2 kPa and 123.8 kPa, respectively. The modified mix's TSR value was 97%, notably exceeding the control mix's 85%, suggesting it has lower susceptibility to moisture.
5. The mix modified with polyethylene exhibited a permeability rate of 4.2 mm/s, compared to 3.0 mm/s for the control mix. This suggests a more interconnected void structure that improves drainage, which is essential for the performance of pervious pavement.
6. The overall performance of the waste polyethylene-modified pervious asphalt indicates its strong potential as a sustainable and durable alternative to conventional pavement systems. Using waste polyethylene at 4% of the bitumen weight not only enhanced technical properties but also promoted efficient waste use.

Chapter 5: CONCLUSION AND RECOMMENDATION

5.1 GENERAL

This chapter provides a comprehensive overview of the key conclusions derived from the experimental studies, analyses, and discussions presented in earlier chapters. It integrates the performance assessment of waste polyethylene-modified pervious asphalt pavement and evaluates how well the research objectives have been met. The main findings concerning material behavior, mechanical strength, permeability, and durability are underscored, highlighting the possible benefits of incorporating waste polyethylene into asphalt mixes. Additionally, the chapter presents targeted recommendations based on the findings to facilitate practical application and stimulate further research in this area. With these conclusions and recommendations, the study seeks to advance the creation of more sustainable and efficient pavement solutions.

5.2 CONCLUSIONS

The experimental work and analysis conducted in this study lead to the following conclusions regarding the enhancement of pervious asphalt pavement performance through the utilization of waste polyethylene-modified binder:

1. In Bangladesh, traditional pavements face significant issues, including a short service life and poor drainage, particularly during the prolonged rainy season, which lasts from seven to eight months. This results in the accumulation of water, deterioration of structures, and increased maintenance demands.

2. Pervious asphalt pavement offers a sustainable solution due to its porous structure, which allows for rainwater infiltration and reduces surface runoff, thereby decreasing the risk of urban flooding.

3. Different concentrations of waste polyethylene were blended into 60/70 grade neat bitumen. Binder tests conducted according to IRC-SP: 53 guidelines revealed that a 4% addition of waste polyethylene was the optimal concentration, demonstrating acceptable levels of penetration, softening point, ductility, viscosity and lower temperature susceptibility.

4. The polyethylene-modified binder bituminous mix outperformed the neat bitumen mix. Based on air voids, Cantabro abrasion loss, and drain-down test results, the optimal binder content (OBC) is between 5.25% and 5.4%.

5. In the Retained Stability Analysis, the neat bitumen mix showed a stability retention of 71.4%, below the threshold. The polyethylene-modified binder mix had a higher stability retention of 90.4%, indicating better moisture resistance. The Marshall stability for the modified mix was 4.70 kN for dry samples and 4.25 kN for conditioned samples, while the neat binder mix recorded 1.86 kN and 1.33 kN, respectively. Under dry conditions, the modified mix was roughly 2.5 times more stable than the neat binder mix and about 3.2 times higher in conditioned conditions.

6. The Water Sensitivity Analysis revealed notable findings. The tensile strength ratio (TSR) for the neat binder mix was 85%, while the modified binder mix had a TSR of 97%, indicating improved moisture resistance. Additionally, the modified binder mix is 2.3 times stronger under dry conditions and 2.6 times stronger after conditioning than the neat binder mix.

7. The permeability test results showed that the modified binder mix had a coefficient of permeability (k) of 4.2 mm/s, compared to 3.0 mm/s for the neat binder mix. This increase in infiltration rate shows that the modified mix has a better interconnected void structure, enhancing drainage performance.
8. Incorporating waste polyethylene enhances both the mechanical and functional characteristics of pervious pavement, while also promoting environmental sustainability by offering a practical reuse solution for non-biodegradable polyethylene waste.

5.3 SUMMARY OF CONCLUSIONS

In summary, using waste polyethylene-modified binder in pervious asphalt pavement effectively addresses durability and drainage issues, particularly in climates like Bangladesh, while supporting waste management efforts. The key conclusions drawn from the comprehensive experimental analysis are outlined below:

1. Waste polyethylene significantly improved binder properties, increasing softening point and reducing temperature susceptibility making it suitable for both the hot summers of northern Bangladesh and cooler regions.
2. Pervious asphalt mixes with modified binder showed higher Marshall stability in both dry and wet conditions, offering a more durable pavement option in rain-prone regions like Bangladesh.
3. Modified mixes exhibited higher Tensile Strength Ratios (TSR), confirming better resistance to moisture damage. This supports long-

term performance, especially in areas with poor drainage or frequent waterlogging.

4. Improved permeability in the modified mixes enhances surface water infiltration, making it effective for stormwater management and reducing urban flooding in congested areas.
5. The use of waste polyethylene in asphalt contributes to better pavement performance while addressing polyethylene waste issues, supporting sustainable and climate-resilient infrastructure development.

5.4 LIMITATIONS OF THE STUDY

This study offers important insights into the effectiveness of pervious asphalt pavement utilizing waste polyethylene-modified binder, but it is important to recognize several limitations:

1. The experiments took place in controlled laboratory environments. As a result, actual behavior—especially in various traffic and environmental situations—may differ.
2. The study primarily focuses on short-term performance metrics, including strength, permeability, and moisture resistance. It does not address long-term factors such as aging, fatigue, and rutting behavior.
3. While the permeability of the modified mix was assessed, the actual clogging behavior from sedimentation or debris accumulation over time was not recorded.

5.5 RECOMMENDATIONS

Considering the present findings, the following recommendations are proposed for future research to enhance the understanding and applicability of waste polyethylene-modified pervious asphalt pavements:

1. Future studies should focus on field-scale trials to evaluate the long-term performance of modified pervious pavements under varying traffic loads and climatic conditions.
2. Research on innovative surface treatments or additives that can reduce the clogging potential while maintaining permeability would enhance pavement functionality over time.
3. Further exploration can be conducted on blending waste polyethylene with other modifiers such as crumb rubber or natural polymers to achieve synergistic performance gains.
4. Establishing locally adaptable design standards and construction guidelines for polyethylene-modified pervious pavements will help in large-scale adoption and implementation.

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