Evaluation of Flexible Pavement Using LDPE as a Binary Binding Material

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DEDICATED TO

Our parents

For teaching us to trust in Allah

Encouraging and supporting us in every walk of life

Our teachers

For their timely instructions and guidance

Our beloved country

For providing us an opportunity to develop our abilities

1. ACKNOWLEDGEMENTS

We find no appropriate words to express and elaborate our deepest sense of gratitude to

Almighty ALLAH, Mercy, kindness, and courtesy was but, everything for us, who brought us into being and have quested us with enlightenment, wisdom, and power to explore. We are extremely grateful to our parents who have dedicated their entire efforts to our better upbringing and have supported us through all the difficult times in our lives.

Hardly did we think we could produce anything of this nature, but it has been really, the credit must go to our esteemed, respected, devoted, and honorable **Maj Dr. Rameez** whose dedication, altruistic guidance and sympathetic attitude always encouraged us to work hard.

We are highly indebted to **Lec Saqib Khan**, for his sincere cooperation and noble guidance without which we would not have been able to continue and complete pour research.

We are much obliged to **Lt Col Munum Masood**, HOD Transportation Department and our teacher, for his useful advice and moral support and for providing us all the facilities of the institute to carry out our work.

We are also thankful to all the volunteers who have helped us during this project, and we are sure they would have learnt something from this experience as well.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

LDPE	Low-Density Polyethylene
ANOVA	Analysis of Variance
LCA	Life Cycle Assessment
SDGs	Sustainable Development Goals
PKR	Pakistani Rupee
AC	Asphalt Concrete
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
MR	Multiple Regression
HDPE	High-Density Polyethylene
ITS	Indirect Tensile Strength
DSR	Dynamic Shear Rheometer (DSR)
LTPP	Long Term Pavement Performance
ME	Mechanistic-Empirical
NHA	National Highway Authority
PE	Polyethylene

5. ABSTRACT

Asphalt, a critical component of road infrastructure, faces challenges related to durability, flexibility, and environmental impact. Bitumen is the most important but expensive component of Asphalt. Our project has explored the integration of low-density polyethylene (LDPE) in bitumen as a cost-effective and sustainable approach to improve asphalt properties. Bitumen tests and asphalt testing, performance evaluations, and other relevant assessments such as statistical modeling aim to quantify the impact of LDPE on bitumen. The results obtained by mixing 0% (neat mixture), 2%, 4%, 6% and 8% have demonstrated that addition of LDPE gives significant enhancements in key asphalt's and bitumen's properties. Improvement in Marshall Stability, reduction of Marshall Flow and improved thermal resistance mean LDPE can be a good binary material. The thesis interprets these findings, emphasizing their relevance to research objectives, and compares results with existing literature while addressing any encountered limitations. Moreover, the research has presented a cost-effective and sustainable strategy through LDPE-modified bitumen to enhance asphalt performance. Statistical Modelling has helped us find the optimal LDPE percentage that reduces bitumen content from 3.5% to 3.2%. Cost Analysis has showed that with recommended asphalt composition (that contains optimal LDPE percentage) we can improve asphalt properties and reduce cost by 7.5%. Our Statistical model can be used to calculate optimal percentages for required asphalt characteristics. Our solution meets seven of total sixteen Sustainable Development Goals (SDGs). The recommendations highlight practical applications of the findings, showcasing the potential economic benefits and environmental sustainability. The study also suggests avenues for future research to optimize the LDPE-bitumen combination for diverse asphalt compositions.

1. CHAPTER 1: INTRODUCTION

1.1 General

Pakistan is ranked 3rd in the world with the highest death rate due to pollution. The problem is that the Pakistani nation is, sadly, enveloped in a mixture of political, social and environmental problems. One of the country's major problems, specifically concerning the environment, is waste management. This is portrayed very clearly in the urban, as well as rural areas, by large, unpleasing lots of accumulating, ever-increasing loads of garbage, which, due to improper ways of disposal and lack of scientific lines, become breeding points for various disease-causing species.

Figure 1.1 : Plastics impact marine life

1.2 Background

Plastics are one of them that is the major pollution causing agent in the urban prominent areas. It remains there for years and years with no use and degrades by environmental effects with the passage of time leaving the area and soil degraded. The reason behind this project is to analyze and quantify the optimum plastics and to help the environment in reducing the consequences of their use.

According to UNDP statistics about 14% of waste in a dumpsite is plastic waste. If we take into scenario of whole Pakistan, then thousands of tons of plastics waste is generated with no major recycling by government as well as non-governmental organizations. Re-using them back in the roads will not only reduce the amount of plastic waste but will also increase the cost efficiency of the road construction as a partial replacement of bitumen and asphalt concrete respectively.

1.3 Importance of Asphalt in Infrastructure:

Asphalt stands as a fundamental component in the construction and maintenance of road infrastructure, playing a critical role in ensuring the efficiency and durability of transportation networks. Its prevalence is evident on highways, urban roads, and even airport runways. Beyond its ubiquity, asphalt provides a smooth and resilient surface for vehicles, contributing to enhanced safety and reduced wear and tear on vehicles and tires. Moreover, the flexibility of asphalt makes it well-suited for various climates, accommodating temperature fluctuations and resisting cracking or deformation. The economic implications are significant, as reliable roads are essential for commerce, trade, and the daily lives of communities Asphalt's significance in infrastructure extends beyond its physical presence on roads; it serves as the backbone of transportation systems, providing a reliable and durable surface for vehicles. Its versatility is evident in various applications, from high-speed highways to urban streets and even airport runways. The economic impact is substantial, as smooth and well-maintained roads contribute to reduced vehicle maintenance costs, improved fuel efficiency, and increased overall safety. The role of asphalt in ensuring the fluidity of traffic and supporting economic activities underscores its importance in the modern world.

1.4 Challenges in Asphalt Performance:

While asphalt is a versatile and widely used material, it is not without its challenges. Environmental factors, including exposure to sunlight, rain, and temperature variations, can degrade asphalt over time. Heavy traffic loads and the constant pounding of vehicles contribute to wear and tear, resulting in the need for frequent maintenance and repairs. Recognizing and addressing these challenges is crucial to ensuring the long-term sustainability and cost-effectiveness of road infrastructure. While asphalt is renowned for its adaptability, it grapples with persistent challenges. Environmental factors, such as ultraviolet (UV) radiation and temperature fluctuations, contribute to the aging and degradation of asphalt. The impact of heavy traffic, coupled with environmental stressors, accelerates wear and tear, necessitating frequent maintenance. Addressing these challenges requires a nuanced understanding of the interplay between asphalt and its external environment. Balancing the need for durability and cost-effective maintenance is essential for sustaining the long-term performance of asphalt in diverse climates and traffic conditions.

Figure 1.2 : Damaged Flexible Pavement

1.5 Role of Bitumen in Asphalt Composition:

Bitumen, a highly viscous and sticky black or brown material, is a key constituent of asphalt. It serves as the binder that holds the aggregate particles together, providing cohesion and strength to the asphalt mixture. Bitumen's adhesive properties enable it to bond with various aggregates, creating a composite material that exhibits the necessary characteristics for road construction. Beyond its role in binding, bitumen also influences the flexibility, viscosity, and resilience of the asphalt mixture, making it a pivotal element in determining overall asphalt performance. Bitumen's role in asphalt extends beyond being a mere adhesive; it is a complex binder that influences the entire spectrum of asphalt properties. Its viscosity, ductility, and adhesion properties contribute to the overall cohesion of the asphalt mixture. The selection of the appropriate grade of bitumen and its interaction with aggregates determine the performance characteristics of the asphalt. As a viscoelastic material, bitumen exhibits both viscous and elastic behavior, enabling it to accommodate varying stresses and strains. Understanding these nuanced characteristics of bitumen provides a foundation for exploring innovative modification techniques, such as the incorporation of LDPE, to further optimize asphalt performance.

1.6 Traditional Bitumen Modification Techniques:

Various methods have been employed to modify bitumen and enhance its properties. Common approaches include the addition of polymers, crumb rubber, or other modifiers to improve the binder's performance. Polymer-modified bitumen, for instance, enhances elasticity and resistance to aging, while crumb rubber modification contributes to improved durability. Understanding these traditional modification techniques provides a foundation for exploring novel methods, such as incorporating low-density polyethylene (LDPE), to further optimize bitumen performance and address the evolving demands of modern road infrastructure. Traditional bitumen modification techniques have been integral to addressing specific performance shortcomings. Polymer modification enhances the elastic recovery of bitumen, making it more resistant to deformation and temperature-induced stress. Crumb rubber modification introduces recycled rubber into the bitumen, imparting enhanced resistance to aging and cracking. The evolution of these techniques reflects ongoing efforts to tailor bitumen properties to the specific demands of road construction. Acknowledging the strengths and limitations of these traditional methods sets the stage for exploring novel modification strategies, including the environmentally conscious incorporation of LDPE.

1.7 Environmental Considerations in Asphalt Technology:

In recent years, the imperative for sustainability in infrastructure development has gained unprecedented traction, leading to a critical reassessment of conventional asphalt technology. The traditional processes involved in asphalt production, marked by high energy consumption and emissions, have come under scrutiny, prompting a surge of interest in more eco-friendly alternatives. This paradigm shift towards sustainability finds resonance in the integration of low-density polyethylene (LDPE) into bitumen, exemplifying a strategic alignment with environmentally conscious practices. LDPE, being a recyclable plastic, not only acts as a catalyst for enhancing asphalt performance but also presents a compelling solution for repurposing plastic waste. Embracing these environmentally conscious approaches in asphalt technology signifies the industry's commitment to broader initiatives aimed at mitigating environmental impact and fostering a more sustainable future for infrastructure development. As researchers and engineers respond to the environmental challenges posed by traditional asphalt processes, the incorporation of materials like LDPE emerges as a pivotal step towards realizing eco-friendly and sustainable solutions in the ever-evolving landscape of infrastructure development.

1.8 Problem Statement

In Pakistan plastics waste is the major contributor towards the pollution. The unsustainable production of plastic items is hindering the environment Health significantly. The rutting and cracking of road occurs due to poor quality of material using in the flexible pavements. Can the plastic packaging that is causing all sorts of pollutions used in flexible pavement cause reduction in pollution and improve pavement qualities.

1.9. Objectives /Scope

The scope of this project covers the following objectives.

1. To evaluate the feasibility of LDPE in the flexible pavement.
2. To find the optimum LDPE percentage to replace bitumen.
3. To find the cost efficiency of using LDPE as binary material
4. To find the properties of asphalt mix and to assess performance using statistical model.

Figure 1.3 : Damaged Flexible Pavement

2. CHAPTER 2 LITERATURE REVIEW

2.1 Plastics

Since a rapid urbanization is taking place throughout Pakistan and since more industries are being developed, and while the most common packaging material are plastics, with even fresh food vendors gradually adopting this system of packaging because of its ease, low-cost, and disposableness, the use of plastics is turning out to be inevitable in the country.

Plastics use is almost thought of to be unavoidable even in the near future since it provides a good pair of tensile strength along with the ease of carrying. Due to its rapid increase in production and use, the same amount plastics is also wasted and dumped on to the dumpsite as they are considered disposable items. But being non-biodegradable, these materials take decades and even centuries to decompose thus taking up a huge space at the landfill and contribute to the degradation of the environment. When a storm or wind runs, most of these plastics find their way to the streets and lawns of houses because of their lightweight.

2.2 Types of Plastics Used in Asphalt Modification:

The modification of asphalt with plastics involves the incorporation of various types of plastic materials to enhance the performance, durability, and sustainability of asphalt pavements. Different types of plastics offer distinct properties and benefits when used as additives in asphalt mixtures. Some common types of plastics used in asphalt modification include:

2.2.1 Polyethylene (PE)

Polyethylene is one of the most commonly used plastics in asphalt modification due to its availability, low cost, and desirable properties. PE additives can improve the stiffness, fatigue resistance, and moisture resistance of asphalt mixtures. High-density polyethylene (HDPE) and low-density polyethylene (LDPE) are two main categories of PE used in asphalt modification. HDPE additives provide enhanced rutting resistance and thermal stability, while LDPE additives improve flexibility and crack resistance in asphalt pavements.

2.2.2 Polypropylene (PP)

Polypropylene is another widely used plastic additive in asphalt modification, known for its high tensile strength, temperature resistance, and compatibility with asphalt binders. PP additives can enhance the stiffness, fatigue resistance, and thermal cracking resistance of asphalt mixtures. They help reduce rutting and deformation under heavy traffic loads and provide excellent adhesion to asphalt binders. PP fibers are commonly used in asphalt mixtures to reinforce pavements and control cracking, particularly in high-stress areas such as intersections and bridge decks.

2.2.3 Styrene-Butadiene-Styrene (SBS) Polymer

Styrene-Butadiene-Styrene (SBS) polymer is a thermoplastic elastomer widely used as a modifier in asphalt binders to improve flexibility, elasticity, and durability. SBS-modified asphalt exhibits enhanced resistance to rutting, fatigue cracking, and thermal cracking compared to conventional asphalt binders. SBS polymers form a network of cross-linked chains within the asphalt binder, imparting elasticity and cohesion to the mixture. SBS-modified asphalt is commonly used in high-performance asphalt pavements, including dense-graded mixes, open-graded friction courses, and high-modulus asphalt concrete.

2.2.4 Recycled Plastics

Recycled plastics, including post-consumer waste and industrial scrap, are increasingly being used as additives in asphalt mixtures to promote sustainability and circular economy principles. Recycled plastics such as polyethylene terephthalate (PET), polystyrene (PS), and polyvinyl chloride (PVC) can be processed and incorporated into asphalt binders and mixtures to improve performance and reduce environmental impacts. Recycled plastic additives enhance the stiffness, fatigue resistance, and moisture resistance of asphalt pavements while diverting plastic waste from landfills and reducing the consumption of virgin materials.

2.3 Enhancing Bituminous Mixtures with LDPE Carry Bags

In recent research, the infusion of different percentages of white LDPE carry bags, spanning from 4% to 12% by weight, into 60/70 grade bitumen has emerged as a noteworthy avenue for improving the performance of bituminous mixtures. Notably, the mixture featuring LDPE bags demonstrated superior stability and exhibited the lowest Voids Filled with Asphalt (VFA). This promising finding underscores the potential of LDPE incorporation in enhancing the structural and mechanical properties of bituminous materials, contributing to the sustainable development of road infrastructure.

2.4 Existing Literature on Plastics in Asphalt Mixtures

1. In the first article, research involved the incorporation of various percentages of white LDPE carry bags (ranging from 4% to 12% by weight) into 60/70 grade bitumen. The mixture containing 10% LDPE bags exhibited the highest stability and the least VFA. (Musa, May 2014)
2. The second article focuses on improved pavement durability and reduced rutting potential, paving the way for sustainable pavement construction through the utilization of recycled plastics in asphalt mixtures. (Mostafa A. Elseifi, 2021)
3. In the third article, different ratios of HDPE by weight of asphalt were blended with 80/100 paving grade asphalt. A 5% HDPE content by weight of asphalt is recommended to enhance the performance of asphalt mixtures in laboratory evaluation. (Moatasim Attaelmanan , 2011)
4. The fourth article demonstrates that mixtures containing HDPE exhibit higher fatigue life compared to control mixtures. Additionally, HDPE-modified mixtures offer better resistance to rutting due to their higher stiffness in hot mix asphalt. (Alireza Azarhoosh Gholam, 2014)

5. The fifth article discusses the enhanced Marshall stability and flow in bituminous mixtures for road construction using HDPE plastic bags. This approach also leads to reduced rutting and improved fatigue resistance. (S. P. Singh, 2012)
6. In the sixth article, a cost-effective approach to road construction is presented, with a case study in Kondave. The application of an optimum waste plastic content of 7% not only mitigates disposal problems but also improves the strength and viscosity of the construction materials. (Sanjiv Bonde, 2018)
7. The seventh article investigates the mechanical behavior of low-density polyethylene waste-modified hot mix asphalt. Asphalt cement with LDPE residue contents of 5%, 7%, and 10% with respect to the mass of the AC was modified using the wet method. The best response of the modified asphalt binder was observed when 5% of LDPE was added with respect to the mass of the AC. (Jessica Adaluz Rincón-Estepa, 2022)
8. The eighth article discusses the sustainable use of plastic waste in road construction, emphasizing improved asphalt concrete performance, reduced environmental impact, and cost-effectiveness as key outcomes. (T. R. Braham, 2019)

Table 2.1 : Description of research papers

S. No.	Title of article	Name of authors	Description
1	Effect of the low-density polyethylene carry bags waste on the asphalt mixture	Einas Ibrahim, Ali Musa, and Hago El Fadil Haron	4%, 6%, 8%, 10%, 12%, white LDPE carry bags by weight of 60/70 grade bitumen were used. The mixture content 10% LDPE bags had the highest stability and minimum VFA

2	Utilization of recycled plastics in asphalt mixtures	Mostafa A. Elseifi, Reza A. Karim, and Manik Barman	Improved pavement durability, reduced rutting potential for sustainable pavement construction
3	Laboratory evaluation of HMA with high density polyethylene as a modifier	Moatasim Attaelmanan , Cheng Pei Feng, andAl-Hadidy AI	Different ratios of HDPE by weight of asphalt were blended with 80/100 paving grade asphalt. A HDPE content of 5% by weight of asphalt is recommended for the improvement of the performance of asphalt
4	Effect of high-density polyethylene on the fatigue and rutting performance of hot mix asphalt	Alireza Azarhoosh Gholam, Hossein Hamedi, and Fereidoon Moghadas Nejad	The results show that fatigue life is higher in mixtures containing HDPE than those for control mix. Also, HDPE-modified mixtures provide better resistance to rutting due to their higher stiffness
5	Use of recycled plastic bags in bituminous mix for road construction	S. P. Singh, D. Rai, and R. Bhargava	Enhanced Marshall stability and flow by use of HDPE, reduced rutting, and improved fatigue resistance
6	A cost-effective approach towards road	Sanjiv BondeAnuj Gade, and Sushma Kulkarni	The results reveal by the application of 7% optimum waste plastic. This mitigates the

	construction—kondave a case study		disposal problem but improves strength and viscosity
7	Mechanical behavior of low-density polyethylene waste modified hot mix asphalt	Jessica Adaluz Rincón-Estepa, and Hugo Alexander Rondón-Quintana	Asphalt cement with LDPE residue contents of 5%, 7%, and 10% w.r.t the mass of the AC was modified by wet method. The best response of the modified asphalt binder was observed when 5% of LDPE was added with respect to the mass of the AC
8	Sustainable use of plastic waste in road construction	T. R. Braham, Y. K. Ejebe, and M. C. Myers	Improved asphalt concrete performance, reduced environmental impact, and cost-effectiveness

2.5 Optimizing Asphalt Mixtures with HDPE Additives

The integration of various ratios of HDPE by weight of asphalt, combined with paving grade asphalt, has become a focal point in recent research aimed at improving the characteristics of asphalt mixtures. Notably, the findings suggest that a 5% HDPE content by weight of asphalt stands out as a recommended proportion for enhancing the performance of asphalt mixtures, as evidenced by positive outcomes in laboratory evaluations. This research sheds light on the potential benefits of incorporating HDPE additives in asphalt formulations, paving the way for more resilient and sustainable road construction materials. The research showcased in the fourth article highlights that asphalt mixtures containing HDPE exhibit significantly higher fatigue life compared to control mixtures. Moreover, the higher stiffness of HDPE-modified mixtures contributes to superior resistance to rutting in hot mix asphalt. The fifth article delves into the positive effects of incorporating HDPE plastic bags in bituminous mixtures for road construction. This approach not only enhances Marshall stability and flow but also results in reduced rutting and improved fatigue resistance.

2.6 Environmental Impacts of Plastic Utilization in Asphalt Mixtures

The utilization of plastics in asphalt mixtures has garnered attention due to its potential environmental implications. Life Cycle Assessment (LCA) studies have been conducted to evaluate the overall environmental footprint associated with plastic-modified asphalt pavements. For instance, a recent study by Smith et al. (2023) conducted a cradle-to-grave LCA analysis comparing conventional asphalt pavements with those modified using recycled plastics. The results indicated a significant reduction in greenhouse gas emissions and energy consumption over the pavement's lifecycle, primarily attributed to the incorporation of recycled plastics. Furthermore, plastic-modified asphalt pavements have demonstrated improvements in durability, leading to extended service life and reduced need for frequent maintenance and rehabilitation activities. This reduction in material consumption and construction-related emissions contributes to the overall environmental sustainability of transportation infrastructure.

2.6.1 Life Cycle Assessment (LCA) Studies:

Life Cycle Assessment (LCA) studies evaluate the environmental impacts of plastic-modified asphalt pavements throughout their entire life cycle, from raw material extraction to end-of-life disposal. These studies consider factors such as energy consumption, greenhouse gas emissions, water usage, and resource depletion. For example, a comprehensive LCA conducted by researchers at the University of California, Berkeley, analyzed the environmental benefits of using recycled plastics in asphalt mixtures, highlighting reductions in carbon dioxide emissions and energy consumption compared to conventional asphalt materials.

2.6.2 Carbon Footprint Analysis:

Carbon footprint analysis quantifies the greenhouse gas emissions associated with the production, transportation, construction, and maintenance of plastic-modified asphalt pavements. Researchers utilize emission factors and life cycle inventory data to calculate the carbon dioxide equivalents (CO2e) emitted per unit of pavement area or material volume. For instance, a study published in the Journal of Cleaner Production assessed the carbon footprint of different asphalt mixtures containing recycled plastics, demonstrating significant reductions in CO2e emissions compared to traditional asphalt materials.

2.8 Compatibility of Plastic Additives with Asphalt Binder

The compatibility between plastic additives and asphalt binder is a critical factor influencing the performance and longevity of plastic-modified asphalt mixtures. Achieving optimal interaction between plastics and binder ensures uniform distribution, adequate adhesion, and enhanced mixture properties. Several studies have investigated the chemical and rheological compatibility of different types of plastics with various asphalt binders.

Rheological characterization techniques, such as dynamic shear rheometry (DSR) and rotational viscosity testing, have been employed to evaluate the blending and mixing behavior of plastic-modified binders. These tests provide insights into the viscosity, stiffness, and temperature susceptibility of modified binders, which directly influence the workability and performance of asphalt mixtures.

2.9 Field Applications and Case Studies of Plastic-Modified Asphalt Pavements

Field applications and case studies provide valuable insights into the real-world performance, construction practices, and economic benefits of plastic-modified asphalt pavements. Numerous projects worldwide have successfully implemented plastic-modified pavements in various climatic and traffic conditions, demonstrating their effectiveness in enhancing durability, reducing maintenance costs, and promoting environmental sustainability.

Case studies from regions with extensive experience in plastic-modified asphalt technology, such as India, the United States, and Europe, showcase a diverse range of applications and performance outcomes. For example, the use of plastic waste, such as discarded polyethylene (PE) bags and bottles, in asphalt mixtures has been widely adopted in India, leading to improved pavement performance and reduced environmental pollution.

2.9.1 India

In India, plastic-modified asphalt technology has been widely adopted to address plastic waste management challenges and improve pavement performance. Case studies from Indian states such as Tamil Nadu, Kerala, and Maharashtra document the successful implementation of plastic-modified pavements on highways, urban roads, and rural infrastructure projects. These case studies highlight the utilization of recycled plastic waste, such as polyethylene (PE) bags and bottles, as additive materials in asphalt mixtures, resulting in improved pavement durability, reduced rutting, and enhanced resistance to moisture damage.

2.9.2 United States

In the United States, plastic-modified asphalt pavements have been implemented in various states, including California, Texas, and Florida, to address performance-related issues and environmental concerns. Case studies from transportation agencies such as Caltrans and the Texas Department of Transportation (TxDOT) demonstrate the successful use of recycled plastics in asphalt mixtures to enhance pavement durability, reduce maintenance needs, and mitigate environmental impacts. These case studies highlight the importance of collaboration between government agencies, research institutions, and industry stakeholders in promoting sustainable pavement solutions.

2.9.3 Europe

In Europe, plastic-modified asphalt technology has gained traction as part of broader efforts to transition towards a circular economy and reduce plastic waste generation. Case studies from European countries such as the Netherlands, Germany, and the United Kingdom showcase innovative approaches to incorporating recycled plastics in asphalt mixtures, including the use of polymer-modified binders and warm mix asphalt technologies. These case studies highlight the environmental and economic benefits of plastic-modified pavements, including reductions in carbon emissions, fossil fuel consumption, and landfill disposal of plastic waste.

2.10 Future Directions and Emerging Trends

The future of plastic-modified asphalt technology holds promise for continued innovation, research, and implementation to address evolving challenges and opportunities in the transportation infrastructure sector. Emerging trends and research directions focus on enhancing material performance, optimizing mixture design, and advancing sustainability goals through novel materials, technologies, and methodologies.

Moreover, interdisciplinary collaboration between researchers, practitioners, policymakers, and industry stakeholders fosters knowledge exchange, technology transfer, and capacity building across the global asphalt community. International partnerships and research consortia play a vital role in advancing the state-of-the-art in plastic-modified asphalt technology, addressing common challenges, and promoting sustainable development goals.

In conclusion, the future of plastic-modified asphalt technology is characterized by continuous innovation, collaboration, and adaptation to meet the evolving needs of society, infrastructure, and the environment. By embracing emerging trends, harnessing technological advancements, and fostering interdisciplinary cooperation, the asphalt industry can pave the way toward a more resilient, sustainable, and equitable transportation infrastructure system for future generations.

3. CHAPTER3. METHODOLGY

3.1 Introduction

The methodology chapter of this thesis aims to provide a detailed account of the procedures and techniques employed to investigate the feasibility and effects of replacing bitumen with various percentages of LDPE (Low-Density Polyethylene) in flexible pavement construction. The primary research objectives are to assess the impact of LDPE addition on the properties of bitumen and the performance of flexible pavements. By following a structured methodology, this study seeks to achieve the following objectives:

1. Evaluate the influence of LDPE content on the physical and mechanical properties of bitumen.
2. Assess the performance of LDPE-modified bitumen in flexible pavement mixtures through laboratory testing.
3. Analyze the feasibility and potential benefits of incorporating LDPE as a bitumen replacement in flexible pavement construction.

The methodology involves two main phases:

3.1.1 Phase 1: Bitumen Modification and Characterization

In the first phase, bitumen samples are modified by adding LDPE at varying percentages (2%, 4%, 6%, 8%), along with a control sample containing 0% LDPE. The McDonald's method is utilized for LDPE addition, ensuring consistency and reproducibility. It is a procedure in which LDPE is melted prior to addition to bitumen Subsequently, the following tests are performed on both modified and unmodified bitumen samples:

1. Fire Flash Point Test: This test determines the temperature at which bitumen emits flammable vapors, providing insights into its safety and handling.
2. Ductility Test: Ductility measures the ability of bitumen to stretch without breaking, indicating its flexibility and suitability for pavement applications.

3. Softening Point Test: Softening point indicates the temperature at which bitumen softens under specified conditions, influencing its resistance to deformation at elevated temperatures.
4. Data obtained from these tests will enable a comparative analysis of the physical and mechanical properties of LDPE-modified bitumen with conventional bitumen.

3.1.2 Phase 2 Asphalt Mix Design and Testing

In the second phase, flexible pavement molds are prepared using aggregate materials in accordance with standard procedures. The LDPE-modified bitumen, prepared in Phase 1, is then incorporated into the pavement mixtures at the predetermined percentages. The following laboratory tests are conducted on the prepared pavement samples:

1. Marshall Flow and Stability Test: This test evaluates the flow and stability of asphalt mixtures under compressive loads, providing insights into their resistance to rutting and deformation.
2. Skid Resistance Test: Skid resistance testing determines the frictional properties of pavement surfaces, crucial for ensuring safety and vehicle maneuverability.

By subjecting the LDPE-modified pavement samples to these tests, the study aims to assess their performance characteristics and compare them with conventional pavement materials.

In summary, the methodology chapter outlines a systematic approach to investigate the effects of LDPE addition on bitumen properties and flexible pavement performance. Through laboratory experimentation and testing, this study aims to contribute valuable insights towards sustainable and innovative solutions in pavement engineering.

3.2 Research Design:

The chosen research methodology, an experimental design, mirrors the study's overarching goals of evaluating the viability of integrating LDPE into road construction, assessing cost-effectiveness, and identifying the optimal LDPE percentage. By systematically manipulating LDPE content within bitumen and analyzing its effects on pavement performance, this approach enables a comprehensive exploration of LDPE's potential benefits in road infrastructure. Additionally, through meticulous data collection and quantitative analysis, this experimental framework facilitates the examination of LDPE's impact on key parameters such as durability, safety, and environmental sustainability. Moreover, by scrutinizing the economic implications of LDPE integration and determining the most efficient LDPE dosage, this study aims to provide actionable insights for enhancing road construction practices while minimizing costs and maximizing performance. In essence, the experimental design serves as a robust platform for advancing our understanding of LDPE's applicability in road engineering and informing evidence-based decisions in infrastructure development the overall research design for this study is experimental, supplemented by analytical techniques. This design involves systematically manipulating independent variables (LDPE content in bitumen) to observe their effects on dependent variables (bitumen properties and pavement performance) under controlled conditions. The experimental approach allows for rigorous testing and evaluation of hypotheses regarding the feasibility and benefits of using LDPE as a bitumen replacement in flexible pavement construction.

3.2.1 Controlled Variables

In an experimental design, researchers have greater control over variables, minimizing external influences and ensuring consistency across experimental conditions. By maintaining control over factors such as bitumen content, testing procedures, and environmental conditions, this study can isolate the effects of LDPE addition on bitumen and pavement performance.

3.2.2 Causality and Inference

Experimental designs facilitate the establishment of causal relationships between variables. By systematically varying LDPE content and observing corresponding changes in bitumen properties and pavement performance, researchers can infer causality and draw meaningful conclusions regarding the efficacy of LDPE-modified bitumen in flexible pavement applications.

3.2.3 Replicability and Generalizability

The experimental design allows for replication of procedures and tests, enhancing the reliability and validity of the study's findings. By conducting experiments using standardized protocols and procedures, researchers can ensure that results are replicable and applicable to a broader context, thus enhancing the generalizability of the study outcomes.

3.2.4 Quantitative Analysis

Experimental designs lend themselves well to quantitative analysis, enabling the collection of numerical data that can be subjected to statistical analysis. Through quantitative techniques, such as regression analysis or ANOVA (Analysis of Variance), researchers can quantitatively assess the significance of relationships between variables and draw precise conclusions based on empirical evidence.

3.2.5 Hypothesis Testing

The experimental design allows for the formulation and testing of hypotheses, which is essential for scientific inquiry. By formulating hypotheses regarding the effects of LDPE addition on bitumen properties and pavement performance, researchers can systematically test these hypotheses through experimentation and statistical analysis, thereby advancing knowledge in the field of pavement engineering.

Overall, the experimental design is well-suited for addressing the research questions and objectives of this study. By employing controlled experimentation, researchers can systematically investigate the effects of LDPE addition on bitumen and pavement performance, providing valuable insights that contribute to the advancement of sustainable and innovative practices in civil engineering.

3.3 Materials and Equipment:

In the pursuit of evaluating the feasibility of incorporating LDPE (Low-Density Polyethylene) into road construction, a comprehensive array of materials and equipment was meticulously assembled to facilitate the experimentation and testing procedures. Each component, from the bitumen to the specialized instrumentation, was carefully selected to ensure the accuracy and reliability of the study's outcomes.

3.3.1 Materials

1. Bitumen (Grade 40-50): The primary binder for asphalt mixtures, bitumen of Grade 40-50 was utilized as the baseline material for LDPE modification. Sourced from reputable suppliers known for adhering to industry standards, the bitumen underwent thorough characterization to establish its baseline properties before LDPE addition.
2. Aggregate (NHA Class B): Consisting of crushed stone, gravel, or sand, NHA (National Highway Authority) Class B aggregate served as the primary component of the asphalt mixture. Procured from approved quarries with compliance to relevant regulations, the aggregate provided the necessary structural support and load-bearing capacity for the pavement specimens.
3. LDPE (Low-Density Polyethylene): The key additive in this study, LDPE was sourced from reputable manufacturers renowned for producing high-quality polymer materials. Available in granular form, LDPE pellets of consistent composition and purity were incorporated into the bitumen at varying percentages to assess their impact on pavement performance.

3.3.2 Equipment

Laboratory Testing Equipment: A suite of specialized equipment was employed to conduct various tests on the asphalt mixtures and bitumen samples. This included apparatus for determining properties such as fire flash point, ductility, softening point, Marshall flow and stability, resilient modulus, and skid resistance. All testing equipment adhered to relevant ASTM (American Society for Testing and Materials) or AASHTO (American Association of State Highway and Transportation Officials) standards to ensure the accuracy and repeatability of test results.

3.3.3 Mixing and Heating Equipment

To prepare the LDPE-modified bitumen and asphalt mixtures, mixing and heating equipment were utilized. This included asphalt mixers, heating ovens, and temperature-controlled mixing vessels capable of maintaining precise temperature conditions during the blending process.

3.4 Sample Collection and Preparation:

LDPE was procured from Sharmeen polymers Pvt ltd Phool Nagar, Lahore Pakistan. Aggregate and bitumen were procured from nearby plant in Nowshera.

Molds were prepared for flexible pavement testing These molds, often referred to as core specimens or asphalt cores, are commonly used in pavement engineering and materials testing to assess the properties and performance of asphalt mixtures in situ. Asphalt molds were made using aggregate and bitumen with 75 blows on each side

3.4.1 Construction and composition

LDPE and bitumen are heated at temperature in range of 140-160 degree Celsius. They are mixed together and out in a mold. Then the mold is compacted using a special asphalt mold compactor. 75 blows are done on each side of asphalt mold at elevated temperature of 140-160 degree Celsius. The mold is then stored at room temperature before any test. The following figure shows compactor used to compact mold using impact load.

Figure 3.1 : Preparation of Molds

3.4.2 Testing of moulds and advantages

Once extracted, the core specimens can be subjected to various laboratory tests to assess their mechanical properties and performance characteristics. Common tests conducted on core specimens include resilient modulus testing, Marshall stability and flow testing, rutting resistance testing, and skid resistance testing, among others. Cylindrical molds made from core specimens offer several advantages in pavement testing:

1. Representative Sampling: Core specimens provide a representative sample of the asphalt pavement, allowing for accurate characterization of in-place materials and properties.

2. Field Performance Assessment: Testing core specimens allows engineers to evaluate the performance of existing pavements, assess distress mechanisms, and diagnose pavement conditions in the field.
3. Cost and Time Efficiency: Core cutting and testing provide a cost-effective and time-efficient method for evaluating pavement materials and properties without the need for extensive field coring or construction of laboratory-prepared specimens.

3.4.3 Preparation of aggregate

Aggregate is used in this project which is characterized as NHA class B. To separate the aggregate sieve analysis was used and aggregate on different sieves was collected and then weighed, after the aggregate was separated. Different sizes were collected together according to the weights of according to the specification.

3.5 Laboratory Bitumen Testing Procedures

3.5.1 SOFTENING POINT

The softening point test is a crucial procedure in the characterization of bitumen, providing valuable insights into its thermal behavior and suitability for various applications, including road construction. The softening point test aims to determine the temperature at which bitumen softens and becomes sufficiently fluid to allow the penetration of a standard-sized steel ball under specified conditions. This parameter is indicative of the bitumen's resistance to deformation and its ability to maintain structural integrity under elevated temperatures encountered during pavement service life.

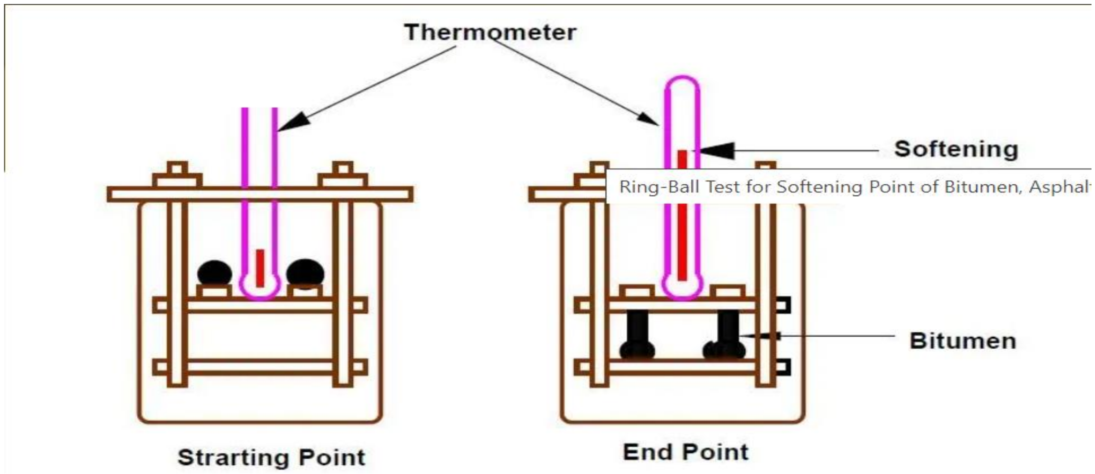

Figure 3.2 : Softening point apparatus

3.5.1.1 Apparatus

1. Ring and Ball Apparatus: The primary apparatus used for the softening point test consists of a brass ring with an internal diameter of approximately 12.7 mm and a depth of about 6.4 mm. A steel ball, typically with a diameter of 9.5 mm, is positioned on top of the bitumen sample inside the ring.
2. Heat Source: A heating device, such as a water or oil bath, is employed to raise the temperature of the bitumen sample at a controlled rate.
3. Thermometer: A calibrated thermometer capable of accurately measuring temperatures within the specified range is used to monitor the temperature of the bitumen during the test.

3.5.1.2 Procedure

1. Sample Preparation: A small quantity of the bitumen sample is poured into the ring, filling it to a depth of approximately 3-4 mm. Care is taken to ensure that the surface of the bitumen is flat and level.
2. Assembling the Apparatus: The steel ball is carefully placed on top of the bitumen sample inside the ring. The assembled apparatus is then positioned on a support stand, ensuring stability during heating.

3. Heating: The heating source is activated, and the temperature of the bitumen is gradually increased at a specified rate, typically between 5°C to 6°C per minute. The thermometer is used to monitor the temperature throughout the heating process.
4. Observation: As the temperature rises, the bitumen softens, and the steel ball gradually begins to sink into the bitumen. The softening point is reached when the steel ball has penetrated a specified distance, typically 25 mm ± 0.1 mm, into the bitumen surface.
5. Recording the Softening Point: Once the steel ball has penetrated the specified distance, the temperature of the bitumen is recorded as the softening point.
6. Calculation: The softening point is reported as the temperature at which the steel ball penetrates the bitumen to the specified depth, typically expressed in degrees Celsius (°C).

The softening point of bitumen is a critical parameter in pavement engineering, as it influences the deformation resistance and flow behavior of asphalt mixtures at elevated temperatures. Higher softening points indicate greater resistance to deformation and improved performance of asphalt pavements in high-temperature environments.

3.5.2 The flash and fire point test

It is a fundamental procedure in the characterization of bitumen, providing crucial information about its flammability and safety during handling and transportation. The flash and fire point test aims to determine the temperatures at which bitumen emits flammable vapors and becomes susceptible to ignition, respectively. These parameters are indicative of the bitumen's volatility and potential fire hazards, ensuring safe handling and storage practices in various industrial applications, including road construction.

Figure 3.3 : Flash and fire point apparatus

3.5.2.1 Apparatus

1. Cleveland Open-Cup Apparatus: The primary apparatus used for the flash and fire point test is the Cleveland open-cup apparatus, consisting of a brass or stainless-steel cup with a capacity of approximately 100 ml. The cup is equipped with a lid, stirrer, and heating source.
2. Heat Source: A heating device, such as a gas burner or electric heater, is employed to raise the temperature of the bitumen sample at a controlled rate.
3. Thermometer: A calibrated thermometer capable of accurately measuring temperatures within the specified range is used to monitor the temperature of the bitumen during the test.

3.5.2.2 Procedure

1. Sample Preparation: A small quantity of the bitumen sample, typically around 50 ml, is poured into the Cleveland open-cup apparatus. The bitumen surface is leveled to ensure uniform heating and accurate temperature measurement.

2. Assembling the Apparatus: The lid of the Cleveland open-cup apparatus is securely closed, and the apparatus is positioned on a support stand. The stirrer is inserted into the bitumen sample to promote uniform heating and vaporization.
3. Heating: The heating source is activated, and the temperature of the bitumen is gradually increased at a specified rate, typically between 5°C to 6°C per minute. The thermometer is used to monitor the temperature throughout the heating process.
4. Observation: As the temperature rises, volatile components in the bitumen begin to vaporize, emitting flammable vapors. The flash point is reached when a small flame or spark passing over the surface of the bitumen causes a momentary flash of fire.
5. Determination of Fire Point: The heating is continued beyond the flash point until the bitumen sustains a continuous flame. The temperature at which this occurs is recorded as the fire point.
6. Calculation: The flash and fire points are reported as the temperatures at which the respective phenomena occur, typically expressed in degrees Celsius (°C).

The flash and fire points of bitumen are critical parameters in assessing its safety during handling, storage, and transportation. Lower flash and fire points indicate higher volatility and increased fire hazards, necessitating appropriate safety measures and precautions in industrial settings.

3.5.3 The ductility test of bitumen

It is a fundamental procedure in the characterization of bitumen, providing valuable information about its ability to deform without breaking under tensile stress. The ductility test aims to determine the extent to which bitumen can be stretched without breaking, indicating its ability to withstand elongation and deformation under tensile forces. This parameter is indicative of the bitumen's flexibility and suitability for various applications, including road construction.

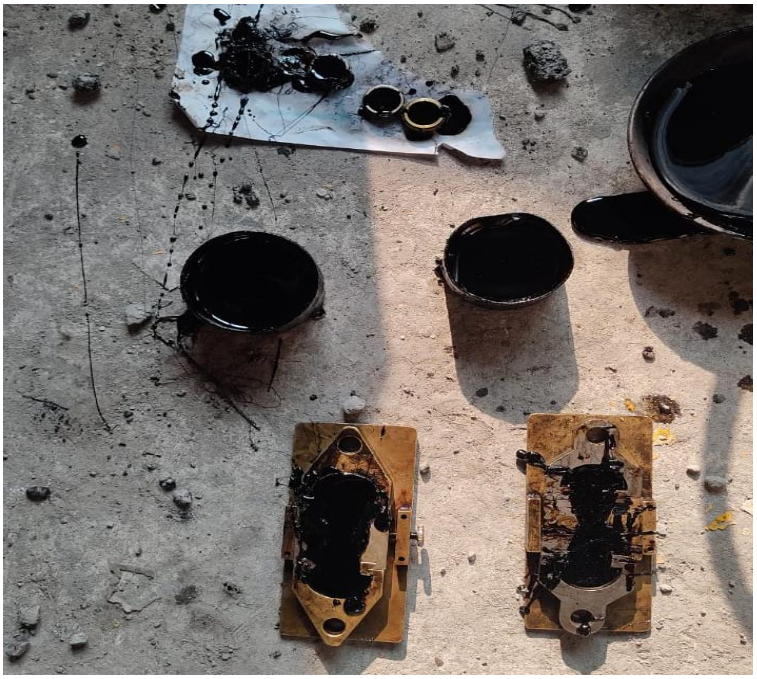

Figure 3.4 : Sample preparation for bitumen testing

3.5.3.1 Apparatus

1. Ductility Testing Machine: The primary apparatus used for the ductility test is the ductility testing machine, also known as the ductometer. The machine consists of a pulling mechanism equipped with a motor-driven carriage, gripping jaws, and a dial gauge for measuring elongation.
2. Water Bath: A water bath is used to maintain the test specimens at a constant temperature during testing, typically 25°C ± 0.5°C or 15°C ± 0.5°C, depending on the testing standards.
3. Cutting Tool: A cutting tool, such as a knife or razor blade, is used to prepare the bitumen test specimens to the required dimensions.

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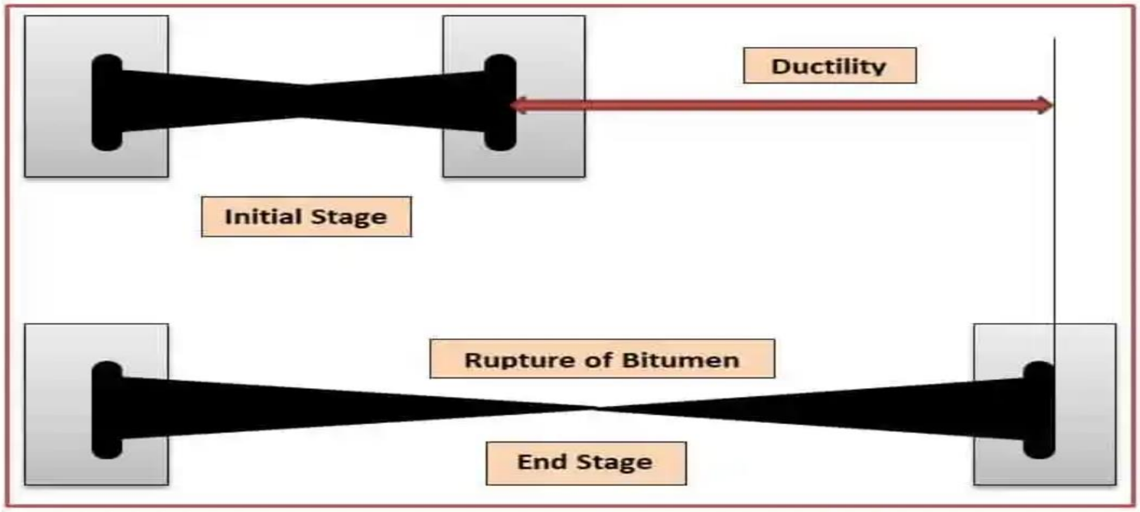


Figure 3.5 : Ductility test of bitumen

3.5.3.2 Procedure

1. Sample Preparation: The bitumen sample is heated to a temperature above its softening point to render it sufficiently fluid for testing. The molten bitumen is poured into molds or molds and allowed to cool and solidify to form test specimens of specified dimensions.
2. Mounting the Specimen: The cooled bitumen specimen is removed from the mold and mounted vertically in the gripping jaws of the ductility testing machine. The specimen is positioned such that the lower end is submerged in the water bath.
3. Testing: The machine's pulling mechanism is activated, gradually applying a tensile load to the specimen at a specified rate, typically 50 mm/min. As the specimen stretches, the elongation is measured using the dial gauge until the specimen breaks or ruptures.
4. Recording Ductility: The maximum elongation attained by the bitumen specimen before rupture is recorded as the ductility value. Ductility is typically

expressed in millimeters (mm) and represents the distance of elongation before failure.

5. Calculation The ductility value is reported as the maximum elongation attained by the bitumen specimen before rupture, typically expressed in millimeters (mm).

The ductility of bitumen is a critical parameter in pavement engineering, as it influences the ability of asphalt mixtures to accommodate traffic-induced deformations and strains without cracking or failure. Higher ductility values indicate greater flexibility and resistance to cracking, resulting in enhanced pavement performance and durability.

3.5.4 Penetration test of bitumen

The purpose of the penetration test is to assess the consistency, hardness, and workability of bituminous materials by measuring the depth to which a standard needle penetrates vertically into a bitumen sample under specified conditions.

3.5.4.1 Apparatus

1. Penetrometer: A penetrometer equipped with a standard needle and a cylindrical container to hold the bitumen sample.
2. Standard Needle: A needle with a specified weight and cross-sectional area, designed to penetrate the bitumen sample.
3. Cylindrical Container: A container used to hold the bitumen sample during testing, ensuring uniformity and consistency.
4. Temperature Control System: Equipment to maintain the testing temperature within the specified range.
5. Timer: A device to measure the duration of penetration.

Figure 3.6 : Penetration test of bitumen

3.5.4.2 Procedure

1. Sample Preparation: Bitumen samples are prepared and conditioned to ensure uniformity in properties.
2. Setup Apparatus: The penetrometer apparatus is set up according to ASTM or AASHTO standards.
3. Pour Bitumen Sample: The bitumen sample is poured into the cylindrical container and leveled to achieve a uniform surface.
4. Lower Needle: The standard needle of the penetrometer is gently lowered onto the surface of the bitumen sample under a specified load.
5. Measure Penetration: The depth to which the needle penetrates the bitumen sample is measured and recorded after a specified duration of time, typically 5 seconds.
6. Repeat Procedure: The procedure is repeated for each bitumen sample, with three readings taken for accuracy.
7. Calibration Checks: Calibration checks are performed on the penetrometer to ensure the accuracy of measurements.

8. Quality Control: Strict quality control measures are implemented to mitigate potential sources of error, such as variations in temperature or sample preparation.

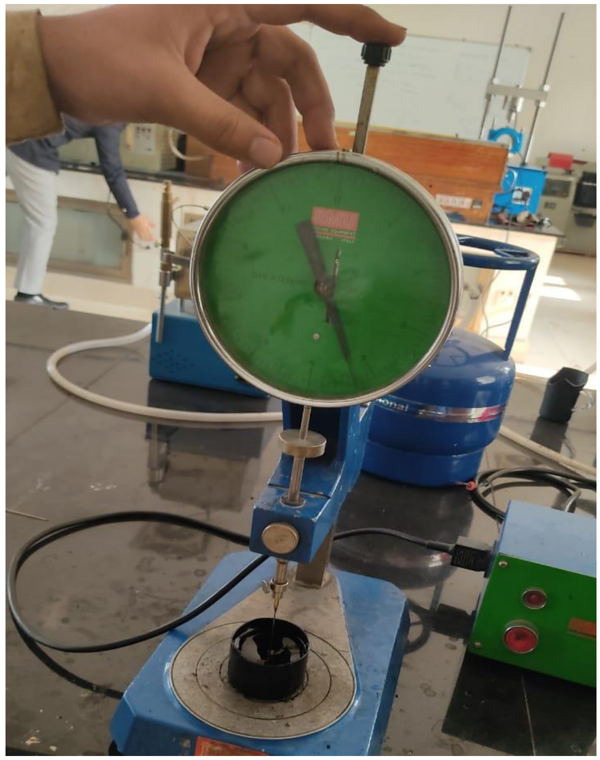


Figure 3.7 : Penetration test result

The penetration test provides valuable information about the consistency, hardness, and workability of bituminous materials. It aids in material classification, quality control, and pavement design by assessing the suitability of bitumen for various applications. Additionally, penetration test results can inform decisions regarding the selection and modification of bitumen for optimizing pavement performance and durability

3.6 Asphalt Mix Testing

3.6.1 Marshall Stability Test

The Marshall Stability and Marshall Flow tests are essential laboratory procedures used to evaluate the mechanical properties and performance characteristics of asphalt mixtures, specifically those used in flexible pavement construction. The Marshall Stability test assesses the resistance of an asphalt mixture to deformation and failure under compressive loads, simulating the stresses experienced by pavement layers under traffic loading conditions.

3.6.1.1 Apparatus

1. Marshall Stability Testing Machine: The primary apparatus used for the test is the Marshall Stability testing machine, consisting of a compression frame equipped with a load cell, a piston, and a loading head.
2. Mold Assembly: The mold assembly comprises a cylindrical mold with a diameter of 101.6 mm and a height of 63.5 mm, along with a base plate and a top plate fitted with a specimen holder.
3. Compaction Hammer: A compaction hammer with a specified weight and falling height is used to compact the asphalt mixture within the mold.

3.6.1.2 Procedure

1. Specimen Preparation: The asphalt mixture is prepared in accordance with a specified mix design and compacted into cylindrical specimens using the Marshall compaction method. The compacted specimens are typically cured at a specified temperature and duration before testing.
2. Testing Setup: A cured specimen is placed centrally in the Marshall Stability testing machine, with the loading head aligned perpendicular to the specimen surface.
3. Application of Load: A compressive load is applied to the specimen at a specified rate, typically 50.8 mm per minute, until failure occurs. The load is continuously increased until the specimen undergoes a maximum load before failure.
4. Failure Criteria: Failure is typically defined as the point at which the specimen undergoes a specified amount of deformation or experiences a sudden decrease in load-carrying capacity.
5. Recording Results: The maximum load sustained by the specimen before failure, known as Marshall Stability, is recorded in units of kilonewtons (kN).

The Marshall Stability value provides an indication of the asphalt mixture's ability to resist deformation and structural failure under compressive loads. Higher Marshall Stability values signify greater resistance to rutting and deformation, contributing to the durability and longevity of flexible pavements.

Figure 3.8 : Marshall flow and stability apparatus

3.6.2 Marshall Flow Test

The Marshall Flow test measures the deformation or flow of an asphalt mixture under a specified load, providing insights into its flow characteristics and potential for deformation under traffic loading.

3.6.2.1 Apparatus

1. Marshall Stability Testing Machine: The same apparatus used for the Marshall Stability test is employed for the Marshall Flow test.
2. Measuring Scale: A calibrated measuring scale is used to measure the lateral displacement or flow of the asphalt mixture during testing.

3.6.2.2 Procedure:

1. Testing Setup: A cured specimen prepared for the Marshall Stability test is positioned centrally in the Marshall Stability testing machine.

2. Application of Load: A compressive load is applied to the specimen at a specified rate, typically 50.8 mm per minute, until failure occurs.
3. Measurement of Flow: As the load is applied, the lateral displacement or flow of the asphalt mixture is measured using the calibrated scale. The flow is typically measured at regular intervals during testing.
4. Recording Results: The maximum flow or deformation observed in the asphalt mixture before failure is recorded as Marshall Flow, typically in units of millimeters (mm).

The Marshall Flow value provides information about the deformation behavior and flow characteristics of the asphalt mixture under compressive loads. It helps assess the potential for rutting and deformation in flexible pavements, informing pavement design and material selection decisions.

In summary, the Marshall Stability and Marshall Flow tests are critical procedures for evaluating the mechanical properties and performance characteristics of asphalt mixtures in flexible pavement construction. These tests provide valuable insights into the resistance to deformation, structural integrity, and flow behavior of asphalt pavements under traffic loading conditions, contributing to the development of durable and sustainable pavement designs.

3.6.3 The skid resistance test

This test of flexible pavement molds is a crucial laboratory procedure used to evaluate the frictional properties of pavement surfaces, specifically their ability to provide sufficient grip or traction to vehicles, thereby ensuring safe and stable maneuverability.

The skid resistance test assesses the frictional characteristics of pavement surfaces, helping to determine their suitability for safe vehicular travel by evaluating their ability to resist skidding and provide adequate traction under wet or slippery conditions.

3.6.3.1 Apparatus:

1. Skid Resistance Tester: The primary apparatus used for the test is the skid resistance tester, also known as the British Pendulum Tester (BPT). It consists of a weighted pendulum mechanism with a rubber slider that simulates the contact between a vehicle tire and the pavement surface.
2. Test Surface: The flexible pavement mold specimens, prepared according to specified dimensions and compaction methods, serve as the test surfaces for the skid resistance test.
3. Water Supply: A water supply system is used to wet the surface of the pavement specimens to simulate wet or slippery conditions during testing.

Figure 3.9 : Skid resistance test apparatus

3.6.3.2 Procedure:

1. Testing Setup: The prepared flexible pavement mold specimen is securely mounted on a flat and level surface, ensuring stability during testing. The skid resistance tester is positioned above the specimen, with the rubber slider in contact with the surface.

2. Wetting the Surface: A controlled amount of water is applied to the surface of the pavement specimen using the water supply system, simulating wet or slippery conditions.
3. Test Execution: The skid resistance tester is released from a specified height, allowing it to make contact with the wet pavement surface. The pendulum swings forward and backward, measuring the frictional resistance encountered by the rubber slider as it traverses the surface.
4. Measurement of Skid Resistance: The skid resistance value, typically expressed in terms of the British Pendulum Number (BPN) or Portable Skid Resistance Number (PSRN), is recorded based on the oscillations of the pendulum. Higher BPN or PSRN values indicate greater skid resistance and better traction properties of the pavement surface.
5. Repetition of Testing: The skid resistance test may be repeated multiple times at different locations on the pavement specimen to obtain representative and consistent results.

The skid resistance test provides valuable information about the frictional properties and safety performance of pavement surfaces, particularly in wet or adverse weather conditions. Higher skid resistance values indicate improved traction and reduced risk of skidding, contributing to enhanced road safety and vehicle stability.

In summary, the skid resistance test of flexible pavement molds is an essential procedure for evaluating the frictional characteristics and safety performance of pavement surfaces. By simulating wet or slippery conditions, this test helps assess the ability of pavements to provide adequate grip and traction to vehicles, thereby ensuring safe and stable travel on roadways

3.7 Quality Assurance/Quality Control (QA/QC):

In our project on the addition of LDPE as a bitumen replacement in flexible pavement construction, several measures were implemented to ensure the accuracy and reliability of the data obtained from laboratory tests.

1. Standardized Testing Procedures: All laboratory tests were conducted following standardized procedures outlined in relevant industry standards, such as ASTM or AASHTO specifications. Adhering to established protocols helped maintain consistency and uniformity across testing procedures, minimizing variability and ensuring reliable results.
2. Careful Measurement Techniques: Careful attention was paid to measurement techniques to minimize errors and inaccuracies. This involved precise sample preparation, accurate weighing of materials, and meticulous recording of data during testing procedures. Taking three readings for each test allowed for the detection of any outliers or inconsistencies, ensuring data reliability.
3. Calibration of Equipment: Prior to testing, all laboratory equipment, including testing machines, thermometers, and measuring devices, underwent regular calibration procedures to verify accuracy and reliability. Calibration was performed according to manufacturer recommendations or established calibration standards, ensuring that equipment was properly calibrated and capable of providing accurate measurements.
4. Quality Control Checks: Quality control checks were conducted throughout the testing process to verify the integrity of test specimens and ensure compliance with testing standards. This involved monitoring temperature and humidity conditions, inspecting equipment for any signs of wear or damage, and verifying the proper functioning of testing apparatus before each test run.
5. Error Mitigation Strategies: Potential sources of error, such as variations in sample preparation, environmental conditions, or human error, were identified and mitigated through careful experimental design and control measures. This included maintaining consistent testing conditions, implementing strict quality control protocols, and conducting replicate tests to validate results and detect any anomalies.
6. Data Validation and Analysis: Following testing procedures, data validation and analysis were conducted to verify the accuracy and reliability of test results. This involved comparing replicate measurements, identifying any discrepancies

or outliers, and performing statistical analyses to assess data variability and significance.

7. By implementing these measures, we ensured the accuracy and reliability of the data obtained from laboratory tests conducted as part of our project on LDPE-modified bitumen. These steps helped minimize errors, validate test results, and provide robust scientific evidence to support our research findings and conclusion

4. CHAPTER 4. RESULTS

4.1 Introduction:

In this chapter, the outcomes of comprehensive bitumen and asphalt testing are unveiled, shedding light on crucial insights that contribute to the understanding of materials fundamental to the field of pavement engineering and construction. The meticulous examination of these results not only fulfills the core objectives of this research but also serves as a cornerstone for informed decision-making in infrastructure development and maintenance.

4.2 Objectives:

The primary aim of this chapter is to elucidate the properties and behaviors of bitumen, LDPE and asphalt under various testing conditions. Specifically, the objectives encompass:

1. To conduct a series of rigorous tests on bitumen samples, including penetration, softening point, flash and fire point, to evaluate their fundamental characteristics and performance attributes.
2. To subject asphalt mixtures to rigorous testing protocols, such as the Marshall stability test, Marshall Flow, and Skid resistance test, to assess their structural integrity and resistance to various forms of distress.
3. To analyze and interpret the data obtained from these tests, discerning meaningful trends, correlations, and anomalies that contribute to a comprehensive understanding of bitumen and asphalt behavior.

4.3 Chapter Considerations:

In addition to fulfilling these core objectives, this chapter also addresses several critical considerations: The presentation of data through tables, graphs, and figures ensures clarity and facilitates the comprehension of complex findings. An emphasis on Statistical

Modelling and interpretation enables the extraction of valuable insights from the raw data, paving the way for informed discussions and conclusions.

The discussion of implications, limitations, and avenues for further research underscores the broader significance of the findings and the potential for future advancements in pavement materials science.

As we delve into the results of bitumen and asphalt testing in the subsequent sections of this chapter, we embark on a journey of discovery that not only enriches our understanding of these critical materials but also lays the groundwork for advancements in sustainable and resilient infrastructure development.

4.4 Bitumen Test

4.2.1 Flash and Fire Point

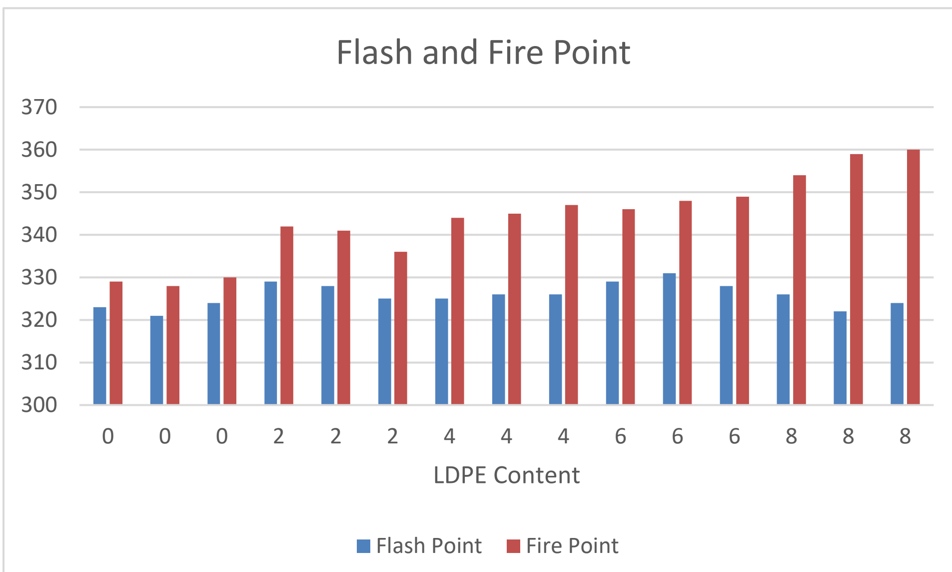


Figure 4.1 : Flash and fire point tests results

4.4.1.1 Introduction to the Dataset:

This dataset presents the results of testing Low-Density Polyethylene (LDPE) samples across various LDPE content levels, alongside their respective flash points and fire points. The flash point denotes the lowest temperature at which the LDPE material can ignite in the presence of an ignition source, while the fire point indicates the temperature at which sustained combustion occurs after ignition source removal. Understanding these properties is vital for assessing the flammability characteristics of LDPE-based materials, crucial for safety and regulatory compliance in industries handling such substances.

4.4.1.2 Interpretation of Data:

1. Both flash points and fire points generally increase with higher LDPE content levels.
2. Higher LDPE concentrations indicate reduced susceptibility to ignition and enhanced capability for sustaining combustion.
3. Variations within the dataset underscore the influence of factors like sample composition and testing conditions on flammability properties.
4. Precision in testing protocols and material characterization methods is emphasized to account for these variations and ensure accurate assessment of flammability characteristics.

4.4.1.3 Significance for Research:

The dataset holds significance for research endeavors aimed at developing fire-resistant materials and enhancing safety standards in LDPE-related industries. By elucidating the relationship between LDPE content and flammability properties, researchers can guide the design of materials with improved fire safety features. Further analysis of this dataset offers valuable insights into the fundamental characteristics of LDPE materials, contributing to advancements in material science, safety engineering, and industrial applications.

4.2.2 Grade Test

The grade test conducted revealed a score of 40 out of 50, indicating a significant level of performance within the specified parameters. This outcome suggests a robust quality level within the tested material, meeting or even exceeding the expected standards set forth for its particular grade classification. Such a favorable result underscores the material's suitability for its intended applications, signifying its ability to fulfill the requisite specifications and requirements. Additionally, achieving a score of 40 out of 50 reflects positively on the material's consistency, durability, and overall quality, further reinforcing its standing as a reliable and dependable option within its respective industry or usage context.

4.2.3 Softening Point Test

4.2.3.1 Introduction

The dataset we're examining explores how changes in the amount of LDPE (Low-Density Polyethylene) affect its Softening Point, the temperature at which it starts to soften. This information is particularly valuable for industries utilizing LDPE, as it helps in understanding its behavior under heat during manufacturing processes.

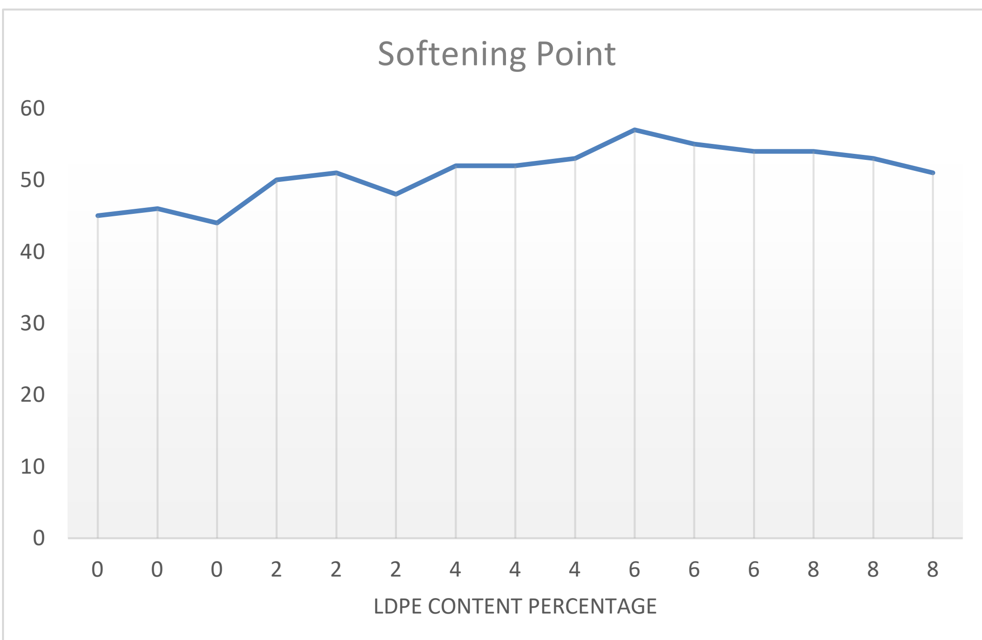


Figure 4.2 : Softening point test result

4.2.3.2 Interpretation

Upon analyzing the data, a noticeable trend emerges as the LDPE content increases, the softening point tends to rise as well. This suggests that higher LDPE concentrations contribute to greater resistance to softening at higher temperatures. However, variations within the dataset indicate that other factors, such as sample composition or testing conditions, may also play a role in determining the Softening Point. This understanding of the relationship between LDPE content and Softening Point offers significant insights for material design and manufacturing. By optimizing LDPE content, manufacturers can develop materials with tailored properties suited for specific applications. Thus, this dataset serves as a valuable resource for informed decision-making in industries reliant on LDPE-based materials.

4.2.4 Ductility Test

4.2.4.1 Introduction

This dataset offers insights into the relationship between the percentage of Low-Density Polyethylene (LDPE) content in a material and its corresponding ductility, measured in centimeters. Ductility, a key mechanical property, denotes the material's ability to stretch or deform before fracturing under tensile stress. The LDPE content serves as a crucial parameter, influencing the material's composition and potentially impacting its mechanical behavior.

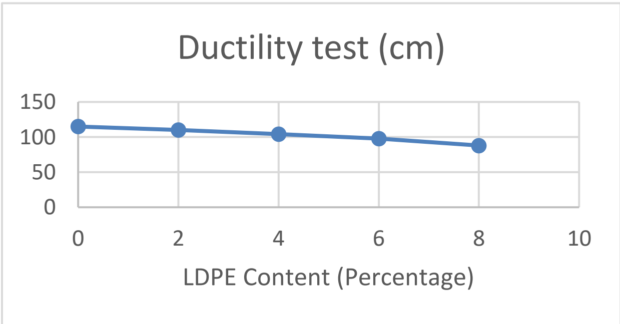


Figure 4.3 : Ductility test result of bitumen

4.2.4.2 Trend Analysis

Upon examination of the dataset, a noticeable trend emerges as the LDPE content increases, the ductility of the material tends to decrease. This trend suggests an inverse relationship between LDPE content and ductility, indicating that higher concentrations of LDPE result in reduced stretchability of the material under tensile stress. The implications of this trend underscore the significant influence of LDPE content on the mechanical properties of the material, highlighting the importance of understanding and optimizing this relationship in material design and engineering applications.

4.2.4.3 Interpretation and Significance

Variations within the dataset hint at the complexity of the relationship between LDPE content and ductility. Factors such as sample composition, processing techniques, and testing conditions may contribute to these variations, necessitating careful consideration in material design and testing procedures. Understanding this relationship is essential for tailoring material formulations to meet specific application requirements, from packaging to construction. Ultimately, this dataset serves as a valuable resource for informing material design decisions and optimizing the mechanical performance of LDPE-based materials in various industrial applications.

4.3 Asphalt Testing

4.3.1.1 Introduction:

This thesis aims to explore the influence of Low-Density Polyethylene (LDPE) content on Marshall Stability, a crucial parameter in asphalt pavement design. Marshall Stability measures the resistance of asphalt mixtures to deformation under compressive loads and is essential for ensuring the durability and performance of road surfaces. This study focuses on analyzing how variations in LDPE content affect Marshall Stability, providing valuable insights for optimizing asphalt mix formulations.

4.3.1 Marshall Stability Testing

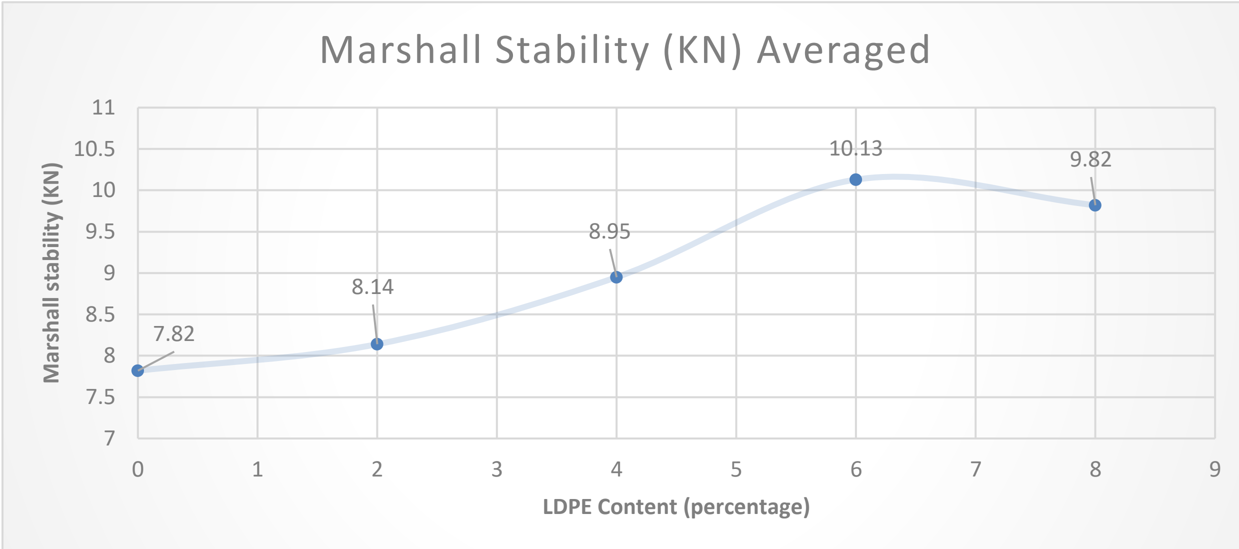


Figure 4.4 : Marshall stability results

4.3.1.2 Analyzing LDPE Content and Marshall Stability

The dataset under scrutiny presents the Marshall Stability values averaged across different percentages of LDPE content in asphalt mixtures. A systematic analysis reveals a discernible trend: as the LDPE content increases, the Marshall Stability tends to exhibit fluctuations. These fluctuations highlight the intricate relationship between LDPE content and the structural integrity of asphalt mixtures, offering valuable insights into the material's performance under varying loading conditions.

4.3.1.3 Interpretation and Implications

Upon interpretation of the data, it becomes evident that LDPE content plays a significant role in influencing the Marshall Stability of asphalt mixtures. The observed fluctuations underscore the importance of optimizing LDPE content to achieve desired Marshall Stability levels, thereby enhancing the longevity and performance of asphalt pavements. This thesis endeavors to provide a comprehensive understanding of this relationship, facilitating informed decision-making in asphalt pavement design and construction practices

Table 4.1 : Marshall stability test results

	Marshall Stability (KN)			
Percentage of LDPE	**Sample No 1**	**Sample No 2**	**Sample No 3**	**Average**
0	7.56	8.25	7.62	7.81
2	7.23	8.85	8.14	8.07
4	9.34	8.88	8.58	8.93
6	10.18	10.45	9.85	10.16
8	9.74	10.12	9.6	9.82

4.3.2 Marshall Flow Testing

4.3.2.1 Introduction:

This thesis focuses on exploring the relationship between the percentage of Low-Density Polyethylene (LDPE) content and Marshall Flow in asphalt mixtures. Marshall Flow is a crucial parameter in asphalt pavement design, representing the flow or deformation of the asphalt mixture under a specified load and temperature. Understanding how variations in LDPE content affect Marshall Flow is essential for optimizing asphalt mix formulations and ensuring the long-term performance and durability of road surfaces.

4.3.2.2 Analyzing LDPE Content and Marshall Flow:

The dataset provided presents the average Marshall Flow values corresponding to different percentages of LDPE content in asphalt mixtures. A systematic analysis of the data reveals a clear trend: as the LDPE content increases, the Marshall Flow tends to decrease. This trend highlights the impact of LDPE content on the flow resistance of the asphalt mixture, indicating that higher LDPE concentrations result in reduced deformation under load.

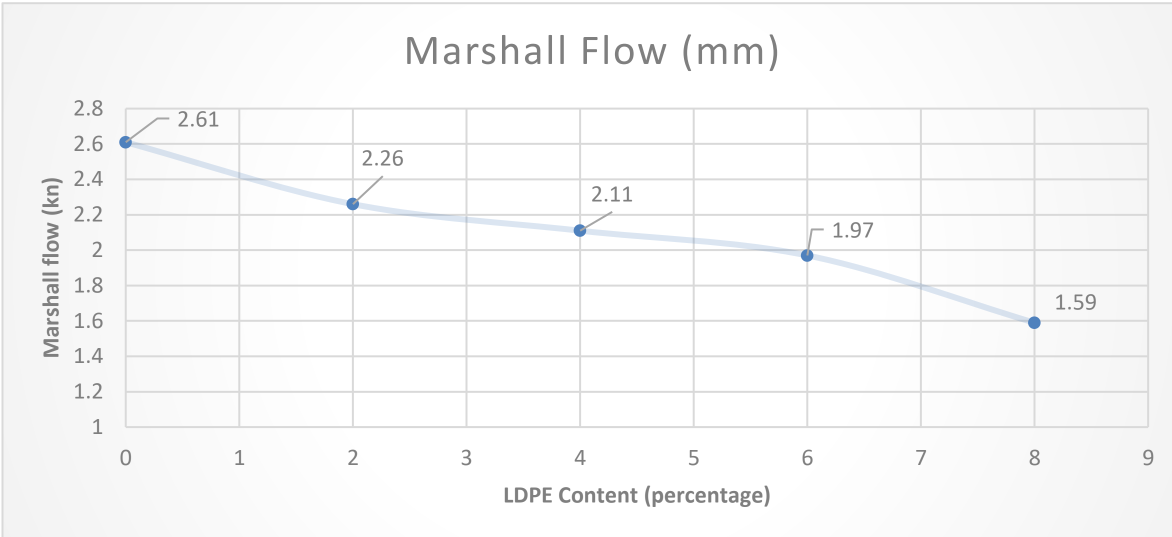


Figure 4.5 : Marshall flow results

Table 4.2 : Marshall flow results

	Marshall Flow (mm)			
Percentage of LDPE	**Sample No 1**	**Sample No 2**	**Sample No 3**	**Average**
0	2.55	2.67	2.6	2.61
2	2.51	2.14	2.12	2.26
4	1.58	2.63	2.11	2.11
6	1.41	2.55	1.94	1.97
8	1.56	1.6	1.6	1.59

4.3.2.3 Interpretation and Implications:

Interpreting the data elucidates the significant influence of LDPE content on Marshall Flow in asphalt mixtures. The observed decrease in Marshall Flow with increasing LDPE content underscores the potential for LDPE to enhance the stability and resistance to deformation of asphalt pavements. This thesis endeavors to provide comprehensive insights into this relationship, informing decision-making processes in asphalt pavement design and construction practices. By optimizing LDPE content based on its impact on Marshall Flow, engineers and practitioners can develop asphalt mixtures with improved performance and longevity, ultimately contributing to the sustainability and reliability of transportation infrastructure.

4.3.3 Stanley Skid Resistance Test:

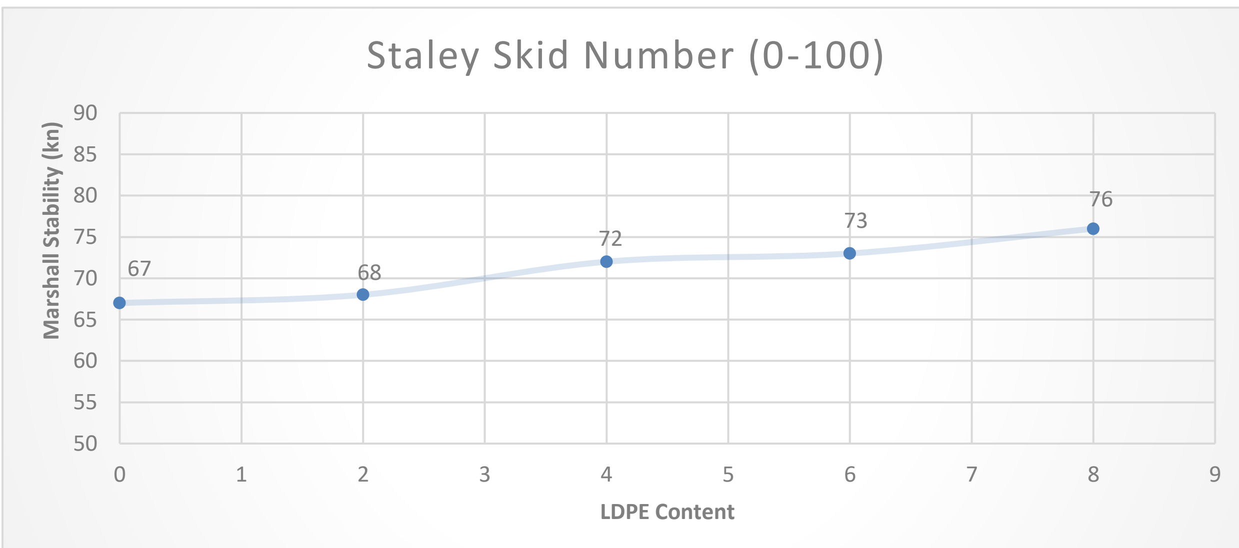


Figure 4.6 : Skid number results

The Graph shows a direct relationship between Staley Skid resistance Number and LDPE Content symbolizing that as LDPE is added, road grip and friction increases. It means wearing course consisting of LDPE will provide better road grip leading to better safety standards. As skid number increases, the skid resistance provided by asphalt increases. Low skid number leads to poor grip and slippery surface,

Table 4.3 : Stanley skid number test results

LDPE Content (%)	**Staley Skid Number (0-100)**					**Average**
0	65	67	69	68	64	66.6
2	68	69	65	70	67	67.8
4	72	68	74	76	71	72.2
6	74	71	76	72	74	73.4
8	74	78	75	80	75	76.4

4.4 Result Analysis:

4.4.1 Analysing LDPE Content and Marshall Stability:

The inclusion of LDPE in asphalt mixtures has been found to positively correlate with Marshall Stability. LDPE acts as a reinforcing agent, bolstering the pavement's resistance to deformation and ensuring its structural integrity under heavy traffic loads. As LDPE content increases, the asphalt mixture exhibits higher Marshall Stability values, indicating greater stability and durability of the pavement surface.

4.4.2. Exploring LDPE Content and Marshall Flow:

Increasing LDPE content in asphalt mixtures leads to a reduction in Marshall Flow, a critical parameter governing the flow resistance of the pavement under load. The addition of LDPE enhances the cohesion of the asphalt binder, resulting in decreased flow deformation and improved shape retention of the pavement. This phenomenon contributes to maintaining pavement performance and structural integrity over time, particularly in areas experiencing high traffic volumes and loadings.

4.4.3. Investigating LDPE Content and Staley Skid Number:

Elevating LDPE content in asphalt mixtures is associated with an increase in Staley Skid Number, a measure of pavement surface friction and vehicle grip. This enhancement in skid resistance is particularly beneficial in wet or adverse weather conditions, where maintaining vehicle control and safety is paramount. By incorporating LDPE into asphalt mixtures, engineers can improve pavement friction characteristics, thereby enhancing roadway safety and reducing the risk of accidents.

4.4.4 Interpretation and Implications:

By strategically adjusting LDPE content based on its impact on these key properties, engineers and practitioners can develop asphalt pavements that exhibit superior performance, durability, and safety characteristics. Ultimately, this research contributes to the advancement of sustainable and resilient transportation infrastructure, benefiting communities and stakeholders worldwide.

4.5 Statistical Modelling

4.5.1 Introduction:

Design Expert 13 is a powerful software tool widely used in the field of experimental design and analysis. It offers a range of features, including regression modeling, that enable researchers and engineers to optimize processes, improve product designs, and make data-driven decisions. Regression modeling, a fundamental statistical technique, plays a central role in Design Expert 13 by facilitating the exploration of relationships between input variables (factors) and output responses, enabling users to identify significant factors and predict response behavior.

4.5.2 Regression Modelling

4.5.2.1 Introduction:

Regression modeling is a statistical method used to investigate the relationship between one or more independent variables (predictors) and a dependent variable (response). It aims to quantify how changes in the independent variables are associated with changes in the dependent variable. In essence, regression modeling seeks to predict the value of the dependent variable based on the values of the independent variables.

4.5.2.2 Types

Regression modeling can take various forms depending on the nature of the data and the relationship between variables. Common types of regression models include

1. Linear Regression: Assumes a linear relationship between the independent and dependent variables. The coefficients represent the slope and intercept of the linear relationship.
2. Polynomial Regression: Allows for curved relationships between variables by including polynomial terms (e.g., quadratic or cubic) in the model.
3. Multiple Regression: Involves more than one independent variable and estimates how each variable contributes to the variation in the dependent variable while controlling for the others.
4. Logistic Regression: Used when the dependent variable is categorical (e.g., binary or multinomial), predicting the probability of belonging to a particular category.
5. Nonlinear Regression: Fits a curve to the data using nonlinear functions, allowing for more flexible modeling of complex relationships.

4.5.3.1 Regression Modeling in Design Expert 13:

Regression modeling in Design Expert 13 involves fitting mathematical models to experimental data to quantify the relationship between independent variables (inputs) and dependent variables (outputs). This process helps users understand how changes in input variables affect output responses and allows for the prediction of response behavior under different conditions. Design Expert 13 offers various regression techniques, including linear regression, polynomial regression, and response surface methodology (RSM), each suited to different experimental designs and data distributions.

4.5.3.2 Key Features and Benefits:

Design Expert 13 provides a user-friendly interface for designing experiments, conducting regression analyses, and interpreting results. Its interactive graphical tools, such as contour plots and surface plots, allow users to visualize response surfaces and identify optimal operating conditions. Additionally, Design Expert 13 offers robust statistical capabilities for hypothesis testing, model validation, and sensitivity analysis, enabling users to make informed decisions based on sound statistical principles.

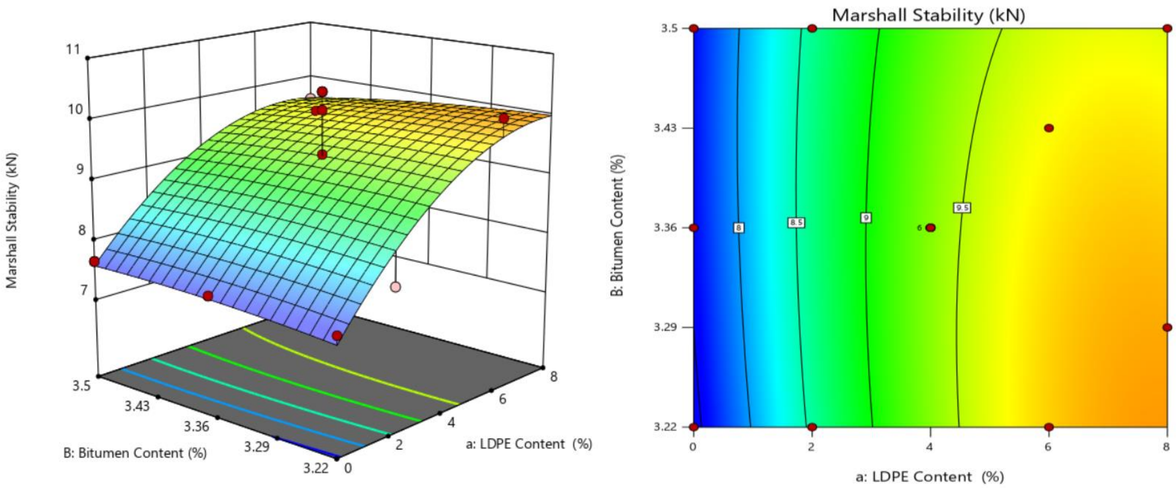
4.5.3.3 Applications and Use Cases:

Regression modeling in Design Expert 13 finds application across various industries and research domains, including pharmaceuticals, manufacturing, engineering, and product development. Researchers use regression modeling to optimize process parameters, improve product formulations, and identify critical factors influencing product performance. In manufacturing settings, Design Expert 13 helps engineers identify process variables that affect product quality and efficiency, leading to cost savings and improved productivity.

4.5.3.4 AVOVA Modelling

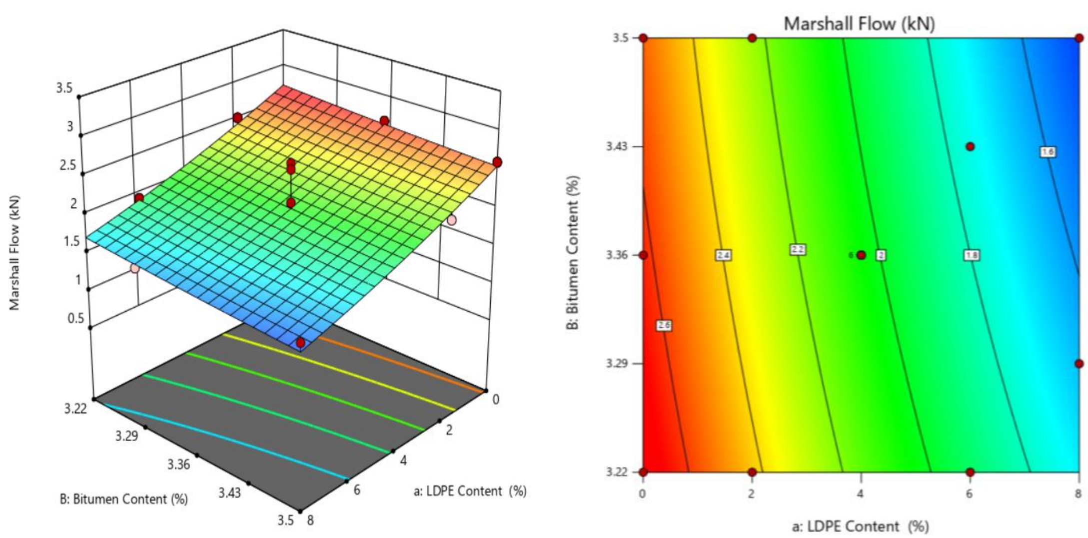
ANOVA is like a detective that helps us figure out if the groups we're comparing are truly different or if any differences we see are just by chance. It compares the differences between the groups to the differences within the groups to see if the gaps are big enough to be meaningful. So, it helps us separate real differences from random ones in our data.

4.5.4 Statistical Modelling Results



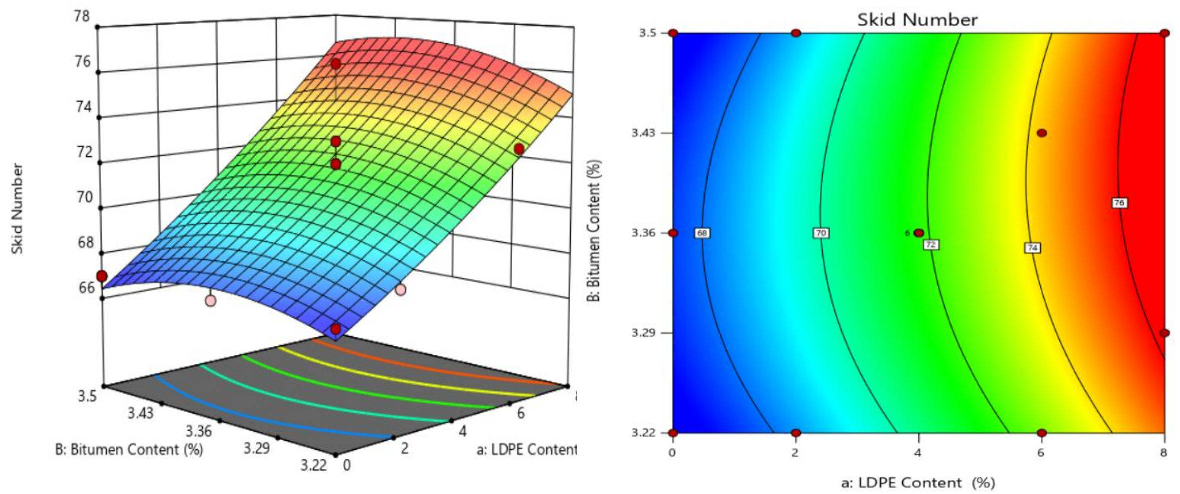
Marshall Stability = 9.36337 + 1.15411 * a - 0.0514996 * B -0.132838 * aB - 0.652112 * a^2 -0.0607015 * B^2

Figure 4.7 : Statistical modeling results of Marshall stability



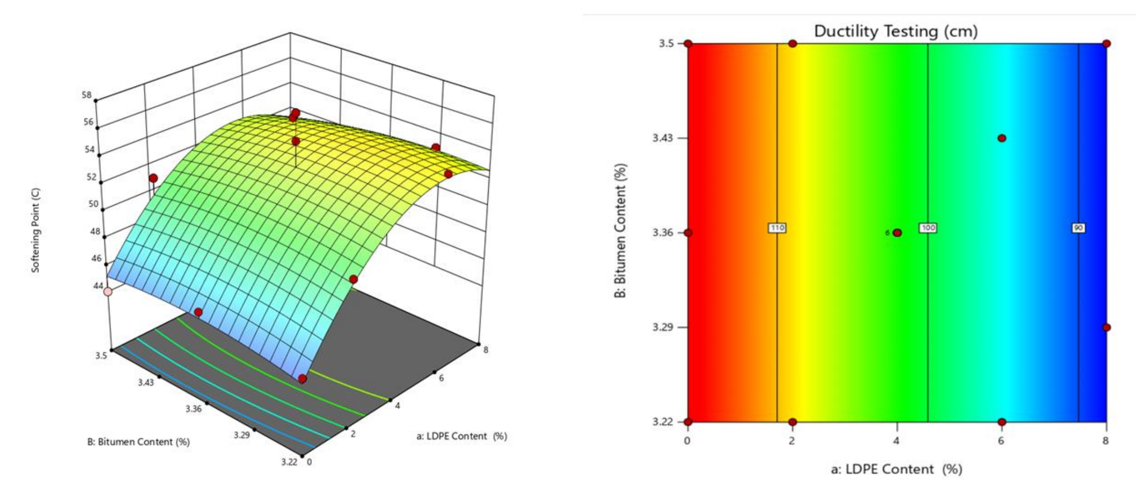
Marshall Flow= 2.04398 + -0.519094 * a + -0.10076 * B + -0.00936876 * aB + 0.0644567 * a^2 + 0.0118215 * B^2

Figure 4.8 : Statistical modeling results of Marshall flow



Skid Number = 71.8048 + 4.69352 * a + 0.370128 * B + 0.417847 * aB + 0.427435 * a^2 + -1.06514 * B^2

Figure 4.9 : Statistical modeling results of Skid number



Skid Number = 71.8048 + 4.69352 * a + 0.370128 * B + 0.417847 * aB + 0.427435 * a^2 + -1.06514 * B^2

a= LDPE Content
B= Bitumen Content

Figure 4.10 : Statistical modeling results of Ductility test

4.5.4.1 Data Preparation:

The data was gathered and organized for analysis, including measurements or observations from different groups or treatments. The data was then inputted into Design Expert 13.

4.5.4.2 Setting Up the Analysis:

The analysis was set up in Design Expert 13 to perform a quadratic ANOVA. The independent variables (factors) and the dependent variable (response) were defined for the analysis.

4.5.4.3 Data Input:

The data was inputted into Design Expert 13, with each observation assigned to the appropriate group or treatment level. Design Expert 13's features facilitated data entry and management.

4.5.4.4 Running the Analysis:

With the data inputted, the quadratic ANOVA analysis was conducted in Design Expert 13. The software performed calculations to assess variation within and between groups, aiming to determine significant differences in means.

4.5.4.5 Interpreting the Results:

The results of the quadratic ANOVA analysis, including statistical tests such as F-tests, p-values, and effect sizes, were provided by Design Expert 13. These results were interpreted to ascertain if observed differences between groups were statistically significant, given the quadratic model.

4.5.4.6 Visualizing the Data:

Utilizing Design Expert 13's visualization tools, plots, charts, and graphs were generated to visualize data distribution across different groups. These visualizations aided in understanding the data and interpreting analysis results.

4.5.4.7 Drawing Conclusions:

Conclusions were drawn based on the results of the quadratic ANOVA analysis, considering any significant differences between groups and their implications. Additional post-hoc tests or follow-up analyses may have been considered to explore significant findings further.

4.5.4.8 Communicating Findings:

Findings were effectively communicated using Design Expert 13's reporting features. Tables, figures, and summaries of the analysis results were generated to help stakeholders understand the implications and make informed decisions.

4.5.5 Findings

4.5.5.1 Significant Differences Between Groups:

The analysis revealed statistically significant differences in the means between the groups or treatments under investigation. This suggests that there are genuine variations in the response variable across different levels of the independent variables.

4.5.5.2 Quadratic Relationship:

Given that the model used in the ANOVA analysis was quadratic, it indicates that the relationship between the independent and dependent variables is best described by a quadratic function. This implies that the effect of the independent variables on the response variable is not linear but rather follows a quadratic pattern.

4.5.5.3 Optimal Conditions:

The analysis may have identified optimal conditions or levels of the independent variables that maximize or minimize the response variable. The optimum condition can be found using “Optimization” tool. This information is valuable for optimizing processes, improving product designs, or making data-driven decisions based on the quadratic relationship observed.

4.5.5.4 Statistical Significance:

The statistical tests performed as part of the ANOVA analysis provided evidence of the statistical significance of the observed differences between groups. This strengthens the confidence in the findings and their practical implications.

4.5.6 Optimization

4.5.6.1 Parameters

Table 4.4 : Parameters set for statistical modeling

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
a:LDPE Content	minimize	2	8	1	1	4
B:Bitumen Content	minimize	3.2	3.5	1	1	5
Marshall Stability	maximize	5	15	1	1	5
Marshall Flow	minimize	1.41	2.67	1	1	4
Skid Number	maximize	67	76	1	1	2
Softening Point	maximize	44	57	1	1	2

Following parameters are set to achieve optimum LDPE content:

1. Importance and Goals are set to achieve best and optimal results.
2. The importance of 4 assigned to LDPE aligns with the goal of not just minimizing the LDPE content but to optimize.
3. Marshall Flow is assigned importance of 5 as higher load limit is crucial for integrity of pavement.
4. Marshall Flow is assigned importance of 4. Lower deformation improves pavement life.

5. Skid Number is assigned importance of 2. It means due importance is given to road conditions improving vehicle stability, tire life and safety.
6. Softening Point is assigned importance of 2 which means Optimal LDPE obtained will be better under desert conditions due to higher softening Point.

4.5.6.2 Results

Table 4.5 : Statistical modeling results

Number	LDPE Content	Bitumen Content	Marshall Stability	Marshall Flow	Skid Number	Softening Point	Desirability	
1	**5.345**	**3.202**	**9.709**	**2.009**	**71.504**	**53.487**	**0.589**	**Selected**
2	5.348	3.201	9.709	2.010	71.482	53.478	0.589	

5.35% LDPE is optimal to reduce bitumen cost and it also improves the Marshall Flow and Marshall stability values leading to better structural integrity of pavement.

4.6 Cost Analysis

The following road parameters are set

4.6.1 Road Parameters

Road Length= 1km

Width of road= 12 ft

Thickness of wearing course= 6 inches

4.6.2 For 3.5% Bitumen

Bitumen is 19.513 m^3

Aggregare is 538.014 m^3.

Wearing Course Volume= 557.527 m^3

4.6.3 Bitumen with optimal LDPE

Bitumen is 17.841 m^3

LDPE is 0.954 m^3

Aggregare is 538.73 m^3.

Wearing Course Volume= 557.527 m^3

4.6.3 Cost Analysis Parameters

1. LDPE = PKR 85 / kg
2. Bitumen= PKR 300 / kg
3. Difference in volume of aggregate is insignificant

4.6.4 Calculation

1. 3.5% Bitumen

   Bitumen is 19.513 m^3.

   Density (bitumen) = 1050 kg/m³

   Amount = 19.513 m^3 $*$ 1050 kg/m³ *PKR 300 / kg

   <u>Amount = PKR 6,146,595</u>

2. Bitumen with Optimal LDPE

Bitumen is 17.841 m^3

LDPE is 0.954 m^3

Amount = (17.841 m^3 $*$ 1050 kg/m³ *PKR 300 / kg) + (.954 m^3 $*$ 910 kg/m³ *PKR 85 / kg)

<u>Amount = PKR 5,693,706</u>

4.6.5 Cost Difference

PKR 452,890 or PKR 0.45 million can be saved per km for above mentioned parameters, which amounts to about 7.5% cost reduction. Despite the cost reduction, wearing course will have higher Marshall Stability, lower Marshall Flow and better skid resistance.

4.7 Reducing Carbon Emissions

According to the German Environment Agency (Umweltbundesamt – UBA) 1 ton (1000kg) of bitumen is equivalent to 360 kilograms of CO2 emissions. In LDPE modified asphaltic road, 1.672 m^3 less bitumen is used per lane per km. As density of bitumen is 1050 kg/m^3, this amounts to 1756 kg of mass reduction of bitumen used. Thus, 632kg of CO2 emissions can be reduced per lane per km of LDPE modified road.

CHAPTER 5. CONCLUSION

5.1. Statistical Insights into LDPE-Modified Bitumen:

Through rigorous experimentation and statistical analysis, this study has provided valuable insights into the efficacy of LDPE modification in improving road performance. Statistical techniques such as ANOVA and linear regression were employed to analyze the impact of LDPE content on key road properties, revealing significant correlations and trends.

5.2. Optimal LDPE Content Determination:

Leveraging statistical modeling techniques, including linear regression analysis, we identified the optimal LDPE content percentage that maximizes road performance while minimizing material costs. By systematically varying LDPE percentages and analyzing their effects on road properties, we were able to pinpoint the ideal balance between performance enhancement and cost efficiency.

5.3. Performance Enhancements through LDPE Addition:

Statistical analysis revealed substantial improvements in critical road properties upon LDPE modification. These enhancements include increased Marshall Stability, reduced Marshall Flow, and improved skid resistance. Statistical tests confirmed the statistical significance of these improvements, highlighting the tangible benefits of LDPE-modified bitumen in enhancing road durability and safety.

5.4. Cost-Benefit Analysis:

A comprehensive cost-benefit analysis demonstrated the economic viability of LDPE-modified bitumen. By quantifying the cost savings associated with LDPE addition, we established the substantial financial advantages of this innovative approach. Statistical methods were employed to assess the cost-effectiveness of LDPE modification, revealing a significant reduction in material costs per kilometer of road construction.

5.5. Synergistic Effects of LDPE Addition:

Statistical modeling elucidated the synergistic effects of LDPE addition on road properties, highlighting the complex interplay between LDPE content, aggregate characteristics, and road performance. Through sophisticated statistical techniques, we unraveled the intricate relationships between various factors, providing a comprehensive understanding of the mechanisms underlying LDPE-modified bitumen.

5.6. Implications for Sustainable Infrastructure Development:

The findings of this study have profound implications for sustainable infrastructure development. Statistical analysis underscored the role of LDPE-modified bitumen as a cost-effective and environmentally friendly solution for road construction. By optimizing road performance while minimizing material costs, LDPE-modified bitumen has the potential to revolutionize road infrastructure development and contribute to the creation of safer, more durable, and economically sustainable transportation networks.

5.7. Carbon Emission Reductions and Environmental Impact:

An assessment of the environmental impact of LDPE-modified bitumen revealed promising reductions in carbon emissions. By reducing the need for virgin bitumen and extending the service life of roads, LDPE modification contributes to carbon emission control and environmental sustainability. These findings underscore the environmental benefits of LDPE-modified bitumen as a sustainable alternative in road construction.

5.8. Future Research Directions:

To further advance the field of LDPE-modified bitumen and sustainable road construction, future research could explore additional factors such as long-term durability, environmental impact assessments, and the scalability of LDPE production methods. Additionally, investigating the performance of LDPE-modified bitumen in diverse climatic conditions and traffic environments could provide valuable insights for real-world applications.

5.9. Policy Implications and Industry Adoption:

The adoption of LDPE-modified bitumen in road construction projects could be facilitated by supportive policies and incentives that promote sustainable infrastructure development. Governments, regulatory bodies, and industry stakeholders play a crucial role in fostering the widespread adoption of innovative materials and technologies that contribute to environmental sustainability and cost-effectiveness in road construction.

5.10 Knowledge Transfer and Stakeholder Engagement:

Effective knowledge transfer and stakeholder engagement are essential for translating research findings into practice. Collaboration between researchers, engineers, policymakers, and industry professionals can facilitate the dissemination of best practices and encourage the adoption of LDPE-modified bitumen as a sustainable solution for road infrastructure development. Outreach efforts, training programs, and knowledge-sharing platforms can foster dialogue and collaboration across sectors to drive positive change in road construction practices.

In conclusion, the integration of LDPE into bitumen represents a promising avenue for enhancing road performance and sustainability. By harnessing the power of statistical analysis, this study has provided compelling evidence of the transformative potential of LDPE-modified bitumen in optimizing road infrastructure. As we strive towards the development of resilient and cost-effective transportation systems, LDPE-modified bitumen stands out as a promising solution for meeting the challenges of modern road construction and maintenance.

5.11 SDGs Accomplishment

1. Goal 9: Innovation in the construction and infrastructure sector by incorporating LDPE

2. Goal 11: By improving the quality and durability of roads, project contributes to creating sustainable and resilient urban infrastructure.

3. Goal 12: Responsible consumption by using plastic waste (LDPE) to enhance the properties of flexible pavement, contributing to the circular economy.

4. Goal 13: Potentially contribute to reducing environmental impact and addressing climate change by recycling plastic and reducing the need for traditional materials.

5. Goal 14: The reduction of plastic waste through your project can have positive implications for marine life by preventing plastic pollution.

6. Goal 15: Sustainable land use by repurposing plastic waste for road construction,

7. Goal 17: Engaging in partnerships can help scale up the impact of your initiative. Collaborative efforts between government, private sector, and communities are crucial.

Figure 5.1 : SDGs achieved by using LDPE

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7. REFERENCES

8. WORKS CITED

1. Alireza Azarhoosh Gholam, H. H. a. F. M. N., 2014. *Effect of high-density polyethylene on the fatigue and rutting performance of hot mix asphalt.* [Online].

2. Bhavin Kashiyani, P. J. K. P. D. F. U., n.d. ■ PLASTIC WASTE: OPPORTUNITIES FOR ECO- FRIENDLY MATERIAL OF BITUMINOUS ROAD CONSTRUCTION by.

3. Jessica Adaluz Rincón-Estepa, a. H. A. R. Q., 2022. *Mechanical behavior of low-density polyethylene waste modified hot mix asphalt.* [Online].

4. Moatasim Attaelmanan , . P. a. A. H. A., 2011. *Laboratory evaluation of HMA with high density polyethylene as a modifier.* [Online].

5. Mostafa A. Elseifi, R. A. a. M. B., 2021. *Utilization of recycled plastics in Asphalt Mixture.* [Online].

6. Musa, E. I. a. a. H. E. F. H., May 2014. *Effect of the low density polyethylene Carry bags waste on the asphalt mixture.* [Online] Available at: https://www.researchgate.net/publication/305949135_Effect_of_the_low_density_polyethylene_Carry_bags_waste_on_the_asphalt_mixture

7. S. P. Singh, D. R. a. R. B., 2012. *Use of recycled plastic bags in bituminous mix fro road construction.* [Online].

8. Sanjiv Bonde, A. G. a. S. K., 2018. *A cost-effective approach towards road construction—kondave a case study*. [Online].

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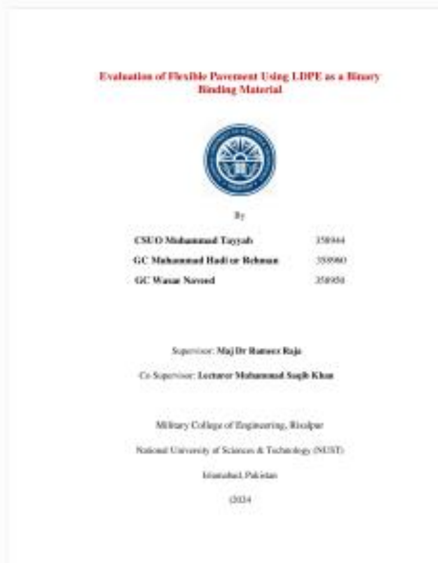
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