APPLICATION OF MEDICAL AND AUTOMOBILE WASTE IN MODIFIED BITUMEN MIX DESIGN

A Project Report submitted in partial fulfillment for the requirement of the Degree

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Under the supervision of

Dr.Amardeep

(Assistant Professor)

By

Ritik Baliyan (211608)

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STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report entitled**"Mixing of Waste Material In Bitumen At Different Percentages For Making Modified Bitumen "**submitted for partial fulfilment of the requirements for the degree of Bachelor ofTechnology in Civil Engineering at**Jaypee University of Information Technology, Waknaghat,**is an authentic record of my work carried out under the supervision of**(Dr. Amardeep).** Thiswork has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report**.**

Signature of Student

Ritik Baliyan

211608

Department of Civil Engineering

Jaypee University of Information Technology, Waknaghat, India

Date – 16 May, 2025

CERTIFICATE

This is to certify that the work which is being presented in the project report title **"Mixing of Waste Material In Bitumen At Different Percentages For Making Modified Bitumen"** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat,**is an authentic record of work carried out by**RitikBaliyan (211608)** during a period from August, 2024, to May, 2025, under the supervision of**Dr. Amardeep,**Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat. The above statement made is correct to the best of our knowledge.

Date:

Signature of Supervisor	Signature of HOD
Dr. Amardeep	Dr. Ashish Kumar
Assistant Professor (SG)	Professor and Head
Department of Civil Engineering	Department of Civil Engineering
JUIT, Waknaghat	JUIT, Waknaghat

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Ritik Baliyan
(211608)

ABSTRACT

More robust and environmentally friendly building materials are needed in the road construction sector due to the increase in traffic on pavements and the speed at which cities are growing. However, the increasing amount of solid waste presents a significant environmental problem. The purpose of this research is to investigate the possibility of using waste materials as bitumen modifiers in order to produce Modified Bitumen (MB) with improved performance characteristics. Different kinds of waste materials, such as crumb rubber, waste plastic, or other industrial leftovers, are mixed with regular bitumen in different amounts (5%, 10%, 15%, and 20%) to see how they affect the final binder's mechanical and physical characteristics.

Standard laboratory tests, including the penetration, ductility, softening point, and viscosity tests, were performed on the modified bitumen samples to examine gains in temperature sensitivity, flexibility, and durability. According to the study, adding waste materials to bitumen not only increases its strength and thermal stability but also promotes recycling and landfill trash reduction, all of which support environmental sustainability. More suitable for the demands of contemporary pavement, modified bitumen can also provide improved resistance to rutting, fatigue, and thermal cracking. By reusing waste materials in a useful way, this research shows that bituminous pavements can be made better while also reducing environmental pollution.

Keywords: Modified Bitumen, Waste Materials, Sustainable Pavement, Bitumen Properties, Recycling

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Bitumen is essential for the construction of flexible pavement because its ability to bind and make waterproofing. Nevertheless, at heavy traffic volume and the disparate climatic condition the unaltered bitumen tends to have its flaws including rutting, cracking, and early aging. To also improve on its performance, bitumen is commonly modified by the use of additives which enhance its endurance, elasticity, and resistance to environmental stress.This research aims at modifying the VG-30 grade bitumen to include waste engine oil and used surgical gloves as new modifiers. Hydrocarbon rich waste engine oil could enhance the workability and the flexibility characteristic of the bitumen. In the meantime, surgical gloves produced from the rubber-based materials such as latex or nitrile can act in favor of increasing the elasticity and thermal stability of the binder. In the present study, the additive mix is blended in different proportions with 0%, 3%, 6%, 9% and 12% to check the effect of such additives on the physical properties and stability value of the mix. This approach does not only seek to improve the performance characteristics of bitumen but also contribute to environmental sustainability by the reuse of non-biodegradable and hazardous waste materials that would end up polluting the environment.

1.2 INTRODUCTION

The importance of enduring and highly performed road surfaces has created great interest in the development of bitumen, the major binder in flexible pavements. The conventional bitumen is also seen to exhibit its limitations when exposed to high traffic and severe weather resulting in early pavement failures. In order to solve these, a wide range of additives are incorporated into bitumen to make it robust, elastic and deformation free. This project is aimed at usage of waste engine oil and used surgical gloves as alternative modifiers for VG-30 grade bitumen. Recovery of the lost properties such as viscosity and flexibility of bitumen from waste engine oil, a hydrocarbons-rich by product would be possible. At the same time, the surgical gloves, which are usually produced from latex or nitrile rubber, possess polymers that are capable of improving the elasticity and thermal resistance of the binder. In the study, the bitumen is made by a mixture of these two waste materials at varying concentrations. 0%, 3%, 6%, 9%, and 12% by weight. The aim is to evaluate what impact these additions have on the performance of bitumen in regard to physical and mechanical properties. This strategy does not only focus on enhancing the quality of the bituminous mix but also delivers an eco-friendly way of re-using the hazardous waste, promoting sustainability as well as innovation in construction of roads.

Table1. 1 List of Modifier used in Bitumen for Modified Bitumen VG30

Modifier Type	**Examples**	**Main Benefits**
Polymer-Based	SBS, EVA, PE, Crumb Rubber, Latex, Nitrile Gloves	Improves elasticity, deformation resistance, and flexibility
Waste-Based	Waste Engine Oil, Used Gloves, Plastic Waste, Used Oil	Enhances flexibility, promotes recycling, lowers environmental impact
Natural Modifiers	Natural Rubber, Lignin, Starch, Cellulose Fibers, Resin	Eco-friendly, improves workability, adds thermal and mechanical stability
Chemical Additives	Phosphoric Acid, Amine Compounds, Zinc Oxide, Sulfur	Enhances bonding, moisture resistance, and aging resistance
Nano-Materials	Nano-Silica, Nano-Clay, Carbon Nanotubes, Graphene Oxide	Improves strength, thermal stability, and durability
Nano-Materials	Lime, Cement, Silica Fume, Stone Dust	Increases stiffness, improves structural strength and moisture resistance

1.3 SUMMARY

The current project aims at improving the performance characteristics of VG-30 grade bitumen by adding two unconventional waste materials to asphalt concrete. waste the engine oil and used gloves for operations. One of the types of the exploration that has ensued arising from the growing demand for more durable, weather-proof, and long lasting surfaces of roads, has been explored to be modified bitumen. Conventional bitumen is frequently lacking when exposed to certain extreme weather conditions and high traffic loads which lead to problems of pavements such as cracking, rutting, and premature deterioration. Overcoming these challenges has become an acceptable practice that involves the modification of bitumen using appropriate additives.

In this study, waste engine oil which has a lot of hydrocarbons used as it has a potential of softening the bitumen and making it flexible. Used surgical gloves, that are usually made out of rubber materials like nitrile or latex, are added for enhancing elasticity, toughness, and thermal degradation. These two materials are environmental pollutants when we do not dispose of them properly hence the use of these materials in the bitumen modification process is sustainable and eco-friendly.

The bitumen samples were prepared by mixing the modifiers in varying proportions—0%,3%, 6%, 9%, and 12% by weight—to observe and compare the changes in physical and mechanical properties. Standard bitumen tests, such as penetration, softening point, ductility, and viscosity, are conducted to evaluate the performance of the modified binders.

The main objective of this research is not only to improve the engineering properties of VG-30 bitumen but also to find an effective method of recycling two types of hazardous waste that are difficult to decompose. By repurposing waste engine oil and surgical gloves, this study contributes to sustainable infrastructure development and promotes environmentally responsible construction practices. The findings from this investigation are expected to support the broader application of waste-based modifiers in road construction, offering both technical and ecological benefits.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Over the last few years, there has been greater focus on achieving sustainable use of resources in the construction industry especially as regards the development of road infrastructure. Traditional bitumen is disadvantageous as regards ageing, environmental effects and ability to withstand extreme weather and heavy traffic in spite of massive application for its water proofing and binding effects. In order to address these problems, researchers are focusing on the modified bitumen formulations that use industrial waste and bio-based additives. These compounds improve performance of bitumen and sustainability of the environment through utilization of wastes. One of such interesting materials and a potential bio-modifier is Black liquor which is a paper pulping process by-product and one with a high concentration of lignin, hemicellulose and other organic substances. The lignin and the black liquor use regarding modification of bitumen has been the concern of several recent research works preferring an enhancement of the material'

Tao et al. (2023) conducted a large-scale research on the rheological characteristics and antigrave processes of bitumen modified by the Paper-black liquor which was published in 'Sustainability' Their research was focused on describing how bitumen and black liquor interact microstructure wise and how this microstructure interaction influences the viscoelastic qualities of the The current research established that when black liquor is added to bitumen, it highly enhanced it in terms of stiffness, elasticity and thermal stability through numerous laboratory trials. In addition, it had excellent resistance to oxidative ageing, which is one of the main sources of pavement degradation. Natural antioxidants such as lignin and phenolic compounds found in black liquor were considered to be the cause of its anti-ageing function. These results shed light on how black liquor has a potential of becoming a sustainable bio-additive for the production of bituminous products that are both high-performing and eco-friendly, and therefore appropriate in modern road construction.

Rachman et al. (2023) investigated the chemical and physical antioxidative effect of asphalt subjected to a treatment with a bio-additive produced from paper pulp black liquor. A publication of the study was in Construction and Building Materials. The purpose of the study was to describe the processes in which the chemical composition of black liquor increases the oxidative stability of asphalt. All the experimental analysis utilized the thermogravimetric analysis (TGA), Fourier-transform infrared spectroscopy (FTIR), and standard binder tests. The results showed that the oxidation process of bitumen was effectively slowed down by the bio-additive, which managed to keep its mechanical and chemical properties in long service periods. This means that by adding black liquor to the asphalt mixtures not only makes them even more endurable but also decreases the necessity of the maintenance process, thus consuming less money and contributing to preservation of the environment. The authors exemplified that bitumen modification can be more sustainable and efficient by using the waste from the paper industry as a value-added component.

Ren et al (2020)extended the use of materials that are lignin rich. The article was published in Journal of Environmental Management. This present study focuses on the application of modified lignin in bio-bitumen coating sheets for waterproofing and protective purposes, unlike previous ones that were based on asphalt pavements. It went through chemical modification to enhance the performance and compatibility of the lignin in the bitumen matrix. The results displayed significant improvements in the overall performance, flexibility, softening point, and resistance to the ageing of the bio-bitumen sheets. Such enhancements are critical in building materials such as industrial flooring, bridge decks as well as roofing are exposed to harsh weather conditions. Also, the authors underlined the eco-friendliness of the lignin and mentioned its availability, biodegradability, and ability to replace petroleum-based bitumen components.

Arafat et al. (2019), who studied how the sustainable lignin can contribute to the resolution of oxidative stress in the paper published in the Journal of Cleaner Production, qualities and ageing characteristics of asphalt binder's mix. The purpose of the study was to establish the long-term durability impact of bitumen whenever lignin is made to combine with it. As noted from the study, the incorporation of the lignin had enhanced the resilience of the asphalt binder to the oxidation thereby reducing the age-related cracking and decay. Besides, the overall performance of the mix was enhanced in terms of resistance to rutting and stiffness especially in hot conditions. The scientists concluded that, lignin is an efficient solution for decreasing the dependence on elements that were obtained through petroleum in asphalt mixes as well as a beneficial additive.

Rachman et al. (2023), that was published in the Construction and Building Materials. The study was carried out with an aim of solving technical and environmental problems using a sustainable valuing of waste from the pulping industry. The effects of lignin in helping asphalt mixtures maintain consistent consistency as well as increasing the binder dispersion and decreasing the binder agglomeration were investigated. The scientists discovered as a result of a sequence of laboratory tests that Kraft lignin improved the flow properties and microstructural uniformity of the modified binder, thus improving its performance during laying and its mixing and compaction. The two benefits of using the lignin are supported by the study. strengthening the behavior of material and incentivizing waste to resources.

Earlier, Zhang et al. (2019) carried out research to investigate the rheological and chemical determination of old lignin-modified bitumen. The main purpose of the authors was to understand the long-term performance of bitumen aged on lignin after synthesizing it under the conditions of ageing. In comparison with untreated binders, the study proved that bitumen modified with lignin retained favorable properties in relation to rheology and improved chemical stability. Lignin hindered the rate of oxidation and thermal degradation, and thus, indicated that it has anti-ageing properties. Based on the rheological analysis that integrated dynamic shear rhinometry (DSR), the modified bitumen remained more elastic and experienced less cracking with time. The study pointed to the potential that lignin has for strengthening the resilience and service life of asphalt pavements, particularly in regions that have considerable climatic temperature changes.

Ren et al. (2021) carried out a more comprehensive and advanced investigation. The mechanisms of the interaction between bitumen and lignin molecules on the macro and nanoscales were studied by this work, both from the perspective of molecular dynamics (MD) simulations and laboratory tests. The work illuminated some of the structural changes at the molecular level through the occurrence of lignin such as improved molecular alignment, greater density, and low free volume. The modified bitumen demonstrated better low-temperature performance, greater viscoelasticity, and better storage stability in an experiment. The hybrid method that was applied in this study will serve as a guide in any future formulations of lignin modified asphalt binders because not only did it confirm the physical advantages of lignin but also a theoretical basis for its behaviour. Lignin is a good by-product of the paper and biomass industries that have attracted more attention in recent times as a possible sustainable asphalt modification ingredient. The resilience and environmental quality of bitumen can significantly be improved through the stiffness, hydrophobicity, and antioxidative character of the lignin i.e. naturally occurring aromatic polymer. Its application in various bituminous formulations has been the subject of an increasing number of scientific studies that have targeted to enhance mechanical performance, ageing resistance and thermal stability.

Kalampokis et al. investigated unique characteristics of bitumen that underwent lignin treatment in a 2022 research that was published in CivilEng. The aim of their research was to find out the effect of lignin on the properties of traditional binder such as penetration, softening point, viscosity and ductility. By laboratory testing, they observed that stiffness and softening point of the bitumen increased with addition of lignin, indicating enhanced properties to resist deformation at a high temperature. The research revealed that lignin can be used to increase the stability and high-temperature capabilities of asphalt binders without compromising its workability due to its similarities with aromatic chemicals contained in bitumen in terms of structure.

Su et al. (2023) gave a detailed study of the mechanism of thermal oxidative ageing of lignin-modified bitumen in Construction and Building Materials, and further explored the aging resistance. Their research was focused on the impact of lignin on the chemical changes of bitumen performed due to oxidative ageing. By stabilizing the free radicals that are formed during oxidation, lignin is a natural antioxidant according to their determination by rheological testing, differential scanning calorimetry (DSC), and Fourier transform infrared spectroscopy (FTIR). Thus, lignin-modified binders exhibited a decreased rate of ageing regardless of its type, and retained enhanced viscoelastic properties. By enlightening the reader on the chemical stability that lignin provides, this study informs of a benefit which is especially useful to pavements that face prolonged heat and UV rays, or are located in a warmer area.

Zhang et al.(2022) Studied another detail of lignin applicability in Journal of Materials in Civil Engineering. Their investigation focused on the effects of bio-oil to the chemistry and rheology of bitumen that has been treated with organosolv lignin. In order to estimate synergistic effects, bio-oil was mixed with organosolv lignin, a high-purity type of lignin, extracted using organic solvents. The findings indicated that while lignin in itself not only promotes rigidity and resilience from ageing but will soften the binder and restore flexibility which is lost when applied alone. This dual modification technique allows the recipe-set of ingredients to produce a balanced binder that is robust to wear and tear, yet workable. The researchers of the optimal dosage and compatibility of additives stressed the importance of composing bitumen for varying traffic and weather conditions. As it is indicated in the IOP Conference Series: Materials Science and Engineering,

Yuanita et al. (2017) Examined the enhancements of polypropylene (PP)-modified bitumen in the use of lignin addition, which went beyond the traditional lignin applications. Not withstanding, polypropylene is a commonly used polymer in preparing bitumen for purposes of enhancing it flexibility and resistance to rutting though more often than not, it lacks ageing resistance. According to the study, the addition of lignin in PP-modified bitumen resulted to the production of a binder which was stiffer and the oxidative degradation was lowered and the thermal stability improved. By lending a hand and counteracting the ageing faults of polypropylene, the obtained lignin produced a more tough and eco-friendlier polymer-bitumen composite.

2.2 RESEARCH GAP

- **Research on Surgical Glove Waste as a Bitumen Modifier Is Limited**

Research on the reuse of medical waste materials, like surgical gloves, in bituminous mixes is severely lacking, despite the fact that several polymer wastes, including polyethylene, polypropylene, and crumb rubber, have been extensively investigated as bitumen modifiers.

- **Lack of Long-Term Ageing and Performance Data:**

Absence of Performance and Long-Term Ageing Data Not enough research has been done on the modified bitumen's long-term aging properties and how it responds to weathering, traffic stress, and time-induced degradation in the actual world.

2.3 OBJECTIVES

1. To evaluate the mechanical characteristics of bituminous mixtures made with modified and regular VG30 bitumen (such as Marshall Stability and flow).

2. To examine how the physical and rheological characteristics of VG30 grade bitumen are affected by adding different proportions of waste engine oil and surgical glove waste.
3. To assess the modified bitumen's performance by the use of common laboratory tests, including viscosity, ductility, penetration, and softening point.

2.4 SUMMARY

The necessity of long-lasting road infrastructure and efficient waste management are two significant worldwide issues that are addressed in this study. When utilised in road construction, conventional bitumen frequently fails in severe weather conditions and with high traffic volumes. However, when incorrectly disposed of, non-biodegradable waste—like spent motor oil and surgical gloves—poses a harm to the environment. The possibility of employing these waste elements as bitumen modifiers in VG30 grade bitumen at different percentages (5%, 10%, 15%, and 20%) is examined in this project. The study is to assess enhancements in bitumen performance and durability through the use of common tests such as penetration, ductility, softening point, and viscosity. By encouraging the reuse of hazardous materials and minimising landfill waste, the project promotes sustainable construction methods and helps create cleaner, more effective infrastructure.

CHAPTER 3
MATERIALS AND METHODOLOGY

3.1 GENERAL

The goal of this project is to improve the performance of road materials and promote environmental sustainability by changing VG30 grade bitumen using used surgical gloves and motor oil. To see how the attributes change, the modifiers are introduced in varying percentages (5%, 10%, 15%, and 20%). Waste engine oil is filtered prior to mixing, and the latex or nitrile gloves are cleaned and shredded. A penetrometer, ring and ball apparatus, ductilometer, and viscometer are among the standard tools and materials used for testing, which assesses penetration, softening point, ductility, and viscosity, respectively. The improved bituminous mix's strength and stability are also evaluated using the Marshall Stability test. For this, mineral filler and coarse and fine aggregates that meet specified gradation are used (cement or stone dust). These components aid in the formation of compacted specimens that are examined for flow and stability values, which reveal the changed mix's ability to support loads.

3.2 MATERIALS USED

All of the materials used for this research were easily obtainable from institutional and local sources, guaranteeing cost-effectiveness and ease of procurement. We purchased VG30 grade bitumen from a local asphalt supplier, which is frequently used in flexible pavement construction. Prior to being shredded for use, surgical gloves were gathered from hospitals and labs and examined to make sure they were sterile and free of biological contamination. Before being mixed with bitumen, waste motor oil was thoroughly filtered to exclude any contaminants like water, dirt, or metal fragments. It was obtained from nearby car repair shops and service stations. A nearby quarry provided the coarse and fine aggregates needed for the Marshall Stability test, which met the requirements of conventional road construction guidelines. Crushing machines or aggregate processing plants provided the stone dust used as a mineral filler. The institute's Civil Engineering Laboratory had all of the standard lab equipment, such as the ductilometer, ring and ball apparatus, viscometer, penetrometer, and Marshall Stability testing machine, as shown in Fig 3.1

3.2.1 BITUMEN

The refining of crude oil produces bitumen, a black, extremely viscous, and sticky hydrocarbon substance. Because of its superior binding qualities, water resistance, and longevity, it is frequently utilized in road construction. The bitumen utilized in this study, VG30 grade, is especially appropriate for areas with moderate to high traffic and temperature fluctuations. Good adherence to aggregates, flexibility in a range of climates, and resistance to deformation are some of its salient features. Because of these characteristics, it is perfect for modification using waste materials or additives like polymers.

Figure3. 1 VG-30 bitumen

Table 3. 1 Basic Properties of Procured Bitumen

Sl. No.	Characteristics	Specified Values	Test Method (IS Code)	Results
i	Penetration at 25°C, 100 g, 5 s, 0.1 mm, Min	45-35	IS 1203	48
ii	Absolute viscosity at 60°C, Poises	2400 – 3600	IS 1206 (Part 2)	3228.2
iii	Kinematic viscosity at 135°C, cSt, Min	350	IS 1206 (Part 3)	559.6
iv	Flash point (Cleveland open cup), °C, Min	220	IS 1448 [P:69]	295.4
v	Solubility in trichloroethylene, percent, Min	99.0	IS 1216	99.1%
vi	Softening point (R&B), °C, Min	47	IS 1205	52.4
vii	Ductility at 25°C, cm, Min	40	IS 1208	65.2

3.2.2 Aggregates

In the Marshall Stability test, aggregates are a vital component of the bituminous mix, and their quality significantly influences the test results. The aggregates used are typically sourced from crushed stone such as granite or basalt (for coarse aggregates), crushed gravel, or natural river gravel. Coarse aggregates are generally retained on the 2.36 mm sieve and pass through the 25 mm sieve. Fine aggregates, on the other hand, consist of natural sand or manufactured sand obtained by crushing rocks, and they pass through the 2.36 mm sieve but are retained on the 75-micron sieve. In addition to coarse and fine aggregates, mineral fillers such as stone dust, lime, cement, or fly ash are used; these pass through the 75-micron sieve and help fill voids and improve the binding properties of the mix. All aggregates must be clean, dry, well-graded, and free from organic impurities or clay. They should also meet specified requirements for properties like specific gravity, water absorption, and abrasion resistance. The use of quality aggregates ensures proper interlocking, durability, and stability of the bituminous mix tested in the Marshall method.

Figure 3. 2 coarse Aggregates b) Fine Aggregates c) Sand used in the study

Table 3. 2 Properties of Aggregates

S No.	Property	Typical Field Value	Remarks / Relevance
1.	Specific Gravity (Coarse)	2.61	Common for granite, basalt, and crushed stone
2.	Specific Gravity (Fine)	2.63	Natural or crushed sand
3.	Water Absorption (%)	0.7	Should be low to reduce bitumen absorption
4.	Los Angeles Abrasion Value (%)	21	Indicates good resistance to abrasion
5.	Aggregate Impact Value (AIV) (%)	15	Lower value indicates higher toughness
6.	Flakiness Index (%)	11	Preferably below 15% for better mix stability
7.	Elongation Index (%)	18	Controls poor particle shape
8.	Stripping Value (%)	14	Measures moisture susceptibility
9.	Aggregate Crushing Value (%)	22	Should be < 30% for high-quality pavement
10.	Fineness Modulus (Fine Agg.)	2.7	Reflects gradation of fine aggregates
11.	Sieve Analysis	2	Depends on layer type (e.g., BC, DBM, etc.)

3.3 MODIFIER

3.3.1 Surgical Gloves

When preparing modified bitumen samples, heat-resistant gloves (Neoprene orAluminized rubber) are used to protect against high temperatures, while chemical-resistant gloves (Nitrile or PVC) safeguard against chemical exposure. For added protection, abrasion-resistant gloves (Kevlar-lined leather) are recommended to prevent punctures when handling rough materials. These gloves ensure both safety and a secure grip during the process.

Figure 3. 3. Surgical gloves used in this research

Table 3. 3 Properties of Surgical Gloves

Property	Typical Value / Description	Purpose / Relevance
Material Type	Heat-resistant Rubber, Neoprene, Kevlar-lined Leather	Protection against heat, cuts, and chemicals
Glove Type	Reusable, Heavy-duty	Withstands harsh construction conditions
Thickness	1.5 – 3 mm	Provides heat and puncture resistance
Temperature Resistance	Up to 250°C (Neoprene/Aluminized gloves)	Suitable for handling hot bitumen
Chemical Resistance	Resistant to hydrocarbons, bitumen, solvents	Prevents degradation from petroleum-based products
Length	300 – 400 mm (elbow-length)	Protects forearms from splashes
Standards Compliance	EN 388 (mechanical), EN 407 (thermal), ASTM F903	Indicates suitability for mechanical and thermal hazards

3.3.2 Waste Engine oil

For the Marshall Stability test, waste engine oil typically comes from used motor oil collected from vehicles, machinery, or industrial equipment. It is sourced from service centres, automotive workshops, or vehicle fleets. This waste oil is often reused in bituminous mixtures as a modifier, aiming to improve the binder's properties and enhance the mix's performance under heavy traffic and temperature conditions. It is essential to filter and process the waste oil to remove impurities before adding it to the bituminous sample for the test.

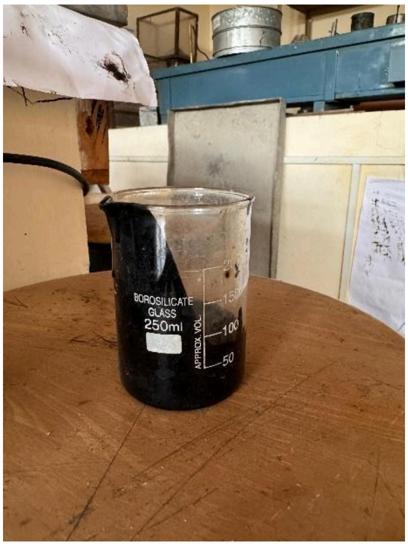


Figure 3. 4 Waste Engine oil used in this research

3.4 Preparation of Modified Bitumen

The preparation of modified bitumen using waste engine oil (WEO) and shredded surgical gloves involves a systematic blending process to ensure uniform dispersion and effective interaction between the base bitumen and the modifiers.VG 30 grade bitumen was selected as the base binder. Initially, the required quantity of bitumen was heated in a high-temperature-controlled mixer to a fluid state at approximately 150°C–160°C. Waste engine oil was added to the hot bitumen in varying proportions of 3%, 6%, 9%, and 12% by weight of bitumen.After thorough mixing for about 15–20 minutes at a constant stirring speed (typically 300–500 rpm), shredded surgical gloves (made of nitrile or latex) were introduced into the blend at the same dosage levels (3%, 6%, 9%, and 12% by weight of bitumen). The gloves were pre-cleaned, dried, and cut into small uniform pieces (about 1–2 mm size) to enhance dispersibility. The mixing process continued for an additional 30–45 minutes to achieve homogeneity, ensuring that both the WEO and glove particles were uniformly distributed within the binder matrix. The temperature was carefully maintained during mixing to prevent degradation of the polymers and ensure proper blending. After preparation, the modified binders were allowed to cool to room temperature and then stored in airtight containers for subsequent testing and characterization.

3.5 METHODOLOGY ADOPTED

3.5.1 Aggregate Gradation

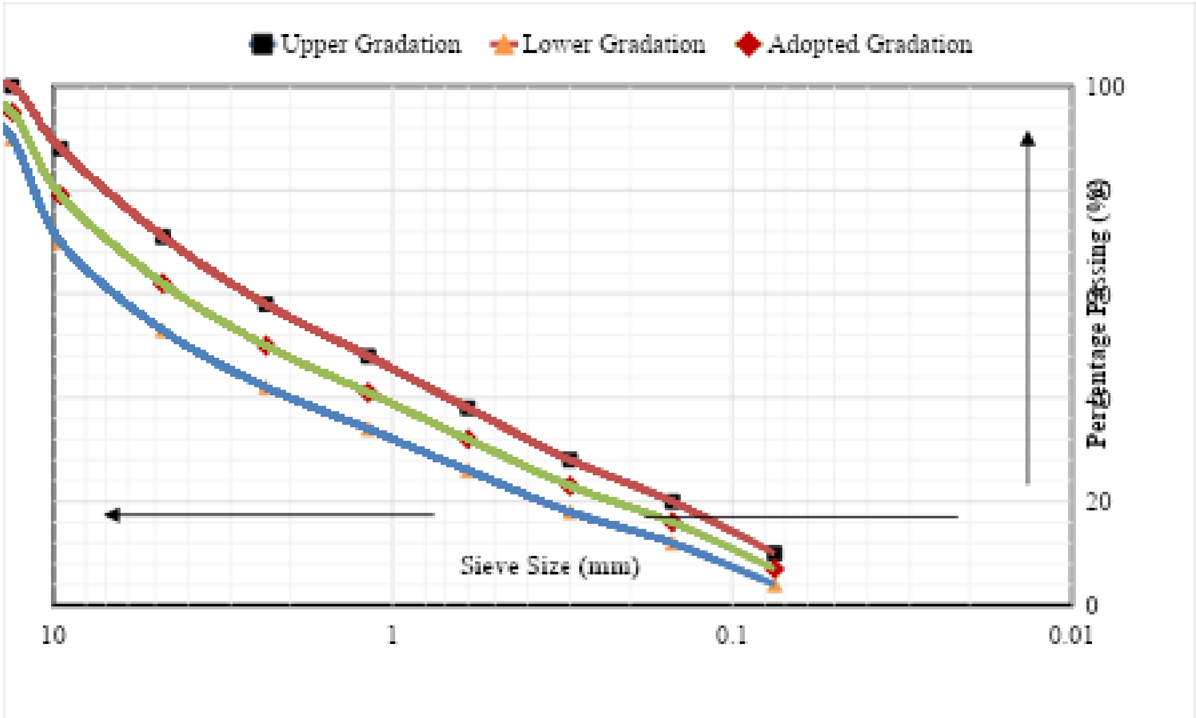


Figure 3. 5 Aggregate Gradation

3.5.2 TESTS ON BITUMEN

1. **Softening point**

The Softening Point Test (IS 1205:1978) uses a ring and ball apparatus Mentioned Below in Figure 3.6 to determine the temperature at which bitumen softens sufficiently to allow a steel ball to fall 25 mm through it. It shows how sensitive the bitumen is to temperature change. as shown in fig

Figure 3. 6 Softening Point of Bitumen

2. **Penetration Test**

The Penetration Test Apparatus shown in Figure 3.7 (IS 1203:1978) calculates how deep, in tenths of a millimeter, a standard needle can pierce bitumen while carrying a 100g load for five seconds at 25°C. It shows how bitumen is hard or consistent.

Figure 3. 7 PenetrationApparatus for bitumen and modified bitumen

3. **Ductility Test**

The Ductility Test Apparatus shown in Figure 3.8 (IS 1208:1978) calculates how many centimeters a typical bitumen sample can stretch before cracking when pushed at a certain temperature and speed. It shows bitumen's flexibility and suppleness.

Figure 3. 8 Ductility test apparatus for bitumen and modified bitumen

4. **Specific Gravity**

The specific gravity of bitumen Apparatus is determined using a pycnometer as shown in Fig 3.9. First, the empty pycnometer is weighed (W_1). Then, bitumen heated to a fluid state is added halfway, and the pycnometer is weighed again (W_2). Distilled water is added to fill the remaining volume, and the total weight is recorded (W_3). Finally, the pycnometer is cleaned, filled fully with water, and weighed (W_4).The test is done at 27°C, ensuring no air bubbles and consistent temperature. This helps determine the density of bitumen compared to water.

Figure 3. 9 Specific Gravity of Bitumen

5.Flash and fire point

The Flash and Fire Point Test which is shown below in Fig 3.10 is conducted to determine the temperature at which bitumen emits enough vapors to ignite (flash point) and sustain combustion (fire point) when exposed to an open flame. This test is crucial for assessing the safety and handling conditions of bitumen during heating and application. The Pensky-Martens closed cup apparatus is commonly used for this test. A higher flash and fire point indicates better thermal stability and lower risk of fire hazards during storage or road construction activities.

Figure 3. 10 flash and fire point apparatus

6. Marshall test

The Marshall Stability Test as shown in fig 3.11 is used to evaluate the strength and flow characteristics of bituminous mixes. In this test, cylindrical specimens are prepared, compacted, and tested under a loading frame to determine the maximum load (stability) they can withstand and the deformation (flow) they undergo. It helps in selecting the optimum bitumen content for pavement design by balancing stability, durability, and flexibility. This test is widely used due to its simplicity and effectiveness in assessing mix performance under traffic loads.

Figure 3. 11 Marshall Stability Test

3.6 STANDARD AND SPECIFICATIONS

The mix design for VG30 modified bitumen follows guidelines set by relevant Indian standards such as

IS 73:2013 – Specifies the requirements for paving grade bitumen (VG30), used as the binder in flexible pavement construction.

IS 383:2016 – Defines specifications for coarse and fine aggregates used in concrete and bituminous mixes, including grading, shape, and strength.

IS 1203:1978 – Covers the penetration test to determine the hardness or consistency of bitumen by measuring the depth a needle penetrates under set conditions.

IS 1205:1978 – Specifies the Softening Point Test (Ring and Ball method) to determine the temperature at which bitumen softens.

IS 1208:1978 – Describes the ductility test, which measures the bitumen's ability to stretch before breaking, indicating elasticity.

IS 1201–1220:1978 – A series of methods for testing tar and bituminous materials, including sample preparation, stability, and flow (used for Marshall Method testing).

ASTM D6927 – Standard test method for Marshall Stability and Flow, widely referenced in Indian practice for mix design validation.

3.7 SUMMARY

In order to improve pavement performance and encourage waste recycling, VG30 grade bitumen was amended using waste surgical gloves and waste motor oil in different amounts (5%, 10%, 15%, and 20%). Before being combined with hot bitumen, the medical gloves were washed, torn, and mixed with filtered waste engine oil. Marshall samples were prepared using a mixture of fine and coarse aggregates and stone dust as a filler. To assess the fundamental characteristics of modified binders, standard tests, including viscosity, ductility softening point, and penetration (IS 1203:1978), were performed. To evaluate strength and flow values, the Marshall Stability test (IS 1201–1220:1978) was conducted. This approach investigated sustainable substitutes for traditional bitumen while guaranteeing consistent testing of material performance.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 GENERAL

The results analysis discusses the effects of varying percentages of waste engine oil and surgical glove waste particles on the character of VG30 bitumen. Normal tests that included Marshall Stability, Viscosity, Ductility, Softening Point and Penetration were carried out. To measure the increases in strength, flexibility, hardiness to temperature changes, and overall performance, the results are compared with those of the traditional bitumen. This analysis shows the potential of these waste materials as environmentally friendly modifiers in the construction of roads and helps in establishing the best combination of blends. Besides waste recycling and the use of environmentally sound methods of road construction, the purpose is to make the bitumen more flexible, thermally stable, and resistant to cracking.

4.2 Physical Properties of Bitumen modified with Surgical gloves

The experimental investigation of bitumen involves testing various mixtures and additives to optimise strength, durability, and sustainability. Table 4.1 presents the physical properties of VG 30 bitumen modified with varying percentages (0% to 12%) of shredded surgical gloves, a polymeric waste material. The unmodified bitumen (0%) serves as the control sample, while the subsequent entries reflect changes in properties due to increasing modifier content. The penetration value decreases from 48 dmm to 39 dmm as the percentage of surgical gloves increases illustrated in figure 4.1, indicating that the bitumen becomes stiffer and harder, which is generally favorable for high-temperature performance and rutting resistance. Simultaneously, the softening point rises from 52.4°C to 55.8°C, showing an improvement in the thermal resistance of the binder.The ductility increases significantly from 68.5 cm to a maximum of 81.4 cm at 9%, suggesting enhanced elasticity and stretchability of the modified binder, which is beneficial for preventing cracks at low temperatures. The specific gravity also shows a gradual rise, indicating denser material formation due to the inclusion of polymeric additives. The flash and fire points increase slightly, implying better safety in handling and application due to improved thermal stability.Overall, the incorporation of surgical glove waste into VG 30 bitumen positively influences key performance parameters. This suggests its potential as a sustainable modifier, offering both environmental benefits by repurposing medical waste and **engineering advantages** in terms of improved binder properties for road construction.

Table 4. 1 Physical properties of surgical gloves modified bitumen

Property Evaluated	0%	3%	6%	9%	12%
Penetration (dmm)	48	45	43	40	39
Softening Point (°C)	52.4	54.2	55.2	56.4	55.8
Ductility (cm)	68.5	75.2	78.5	81.4	79.3
Specific Gravity	1.03	1.04	1.05	1.06	1.05
Flash Point (°C)	297.5	298.5	299.5	301.5	300.1
Fire Point (°C)	318.5	319.2	320.1	321.1	319.5

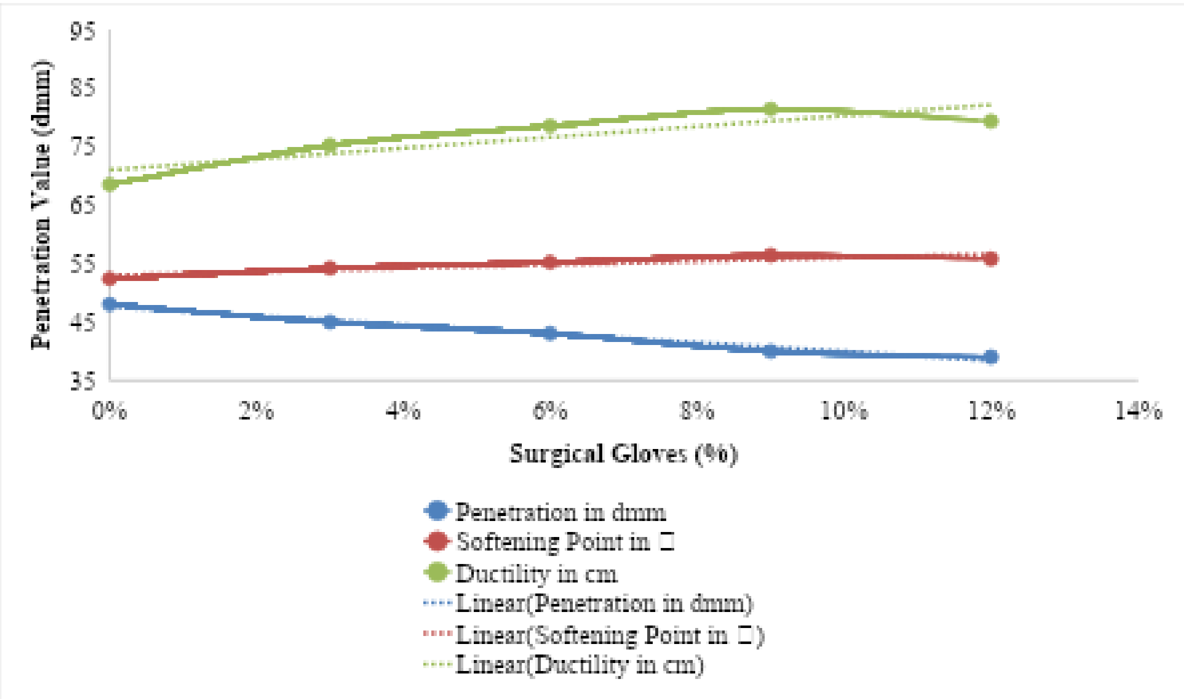


Figure 4.1 Penetration softening point and ductility values of bitumen modified with surgical gloves

4.3 Physical Properties of Bitumen modified with Waste engine oil

Table 4.2 presents the variation in key physical properties of bitumen with increasing percentages of waste engine oil (WEO) as a modifier, from 0% (unmodified) to 12%. The properties evaluated—penetration, softening point, ductility, specific gravity, flash point, and fire point—are essential for understanding the behavior and performance of bitumen under service conditions.As the WEO content increases, the penetration value rises from 48 dmm (0%) to 57 dmm (12%) shown in figure 4.2, indicating a softening effect on the bitumen. This suggests that WEO acts as a fluxing agent, reducing the hardness of bitumen and making it more pliable. Concurrently, the softening point decreases from 52.4°C to 48.4°C at 9%, before slightly increasing to 49.0°C at 12%, reflecting a reduction in temperature susceptibility but also a potential compromise in high-temperature stability.The ductility of the bitumen, which indicates its flexibility and elongation capacity, decreases with increasing WEO, dropping from 68.5 cm at 0% to 55.6 cm at 9%, then slightly increasing to 57.7 cm at 12%. This trend shows that while WEO increases softness, it may reduce the cohesive strength of the binder, which could affect crack resistance at low temperatures.Specific gravity gradually declines from 1.03 to 1.00 with increased WEO content, consistent with the addition of a lighter material. Flash and fire points, which are critical for handling and safety, slightly decrease with WEO addition, from 297.5°C to 293.5°C (flash) and 318.5°C to 315.9°C (fire) at 9%, then show a marginal increase at 12%. This indicates a modest reduction in thermal stability due to the volatile components in WEO.In summary, the data suggests that waste engine oil softens the bitumen and modifies its physical characteristics, making it more workable and flexible. However, excessive WEO (beyond 9%) may compromise high-temperature performance and reduce thermal stability. Thus, careful control of dosage is necessary to achieve desired performance without sacrificing durability or safety.

Table 4. 2 Physical properties of surgical gloves modified bitumen

Property Evaluated	**0%**	**3%**	**6%**	**9%**	**12%**
Penetration (dmm)	48	51	53	56	57
Softening Point (°C)	52.4	50.6	49.6	48.4	49.0
Ductility (cm)	68.5	61.8	58.5	55.6	57.7
Specific Gravity	1.03	1.02	1.01	1.00	1.01
Flash Point (°C)	297.5	296.5	295.5	293.5	294.9
Fire Point (°C)	318.5	317.8	316.9	315.9	317.5

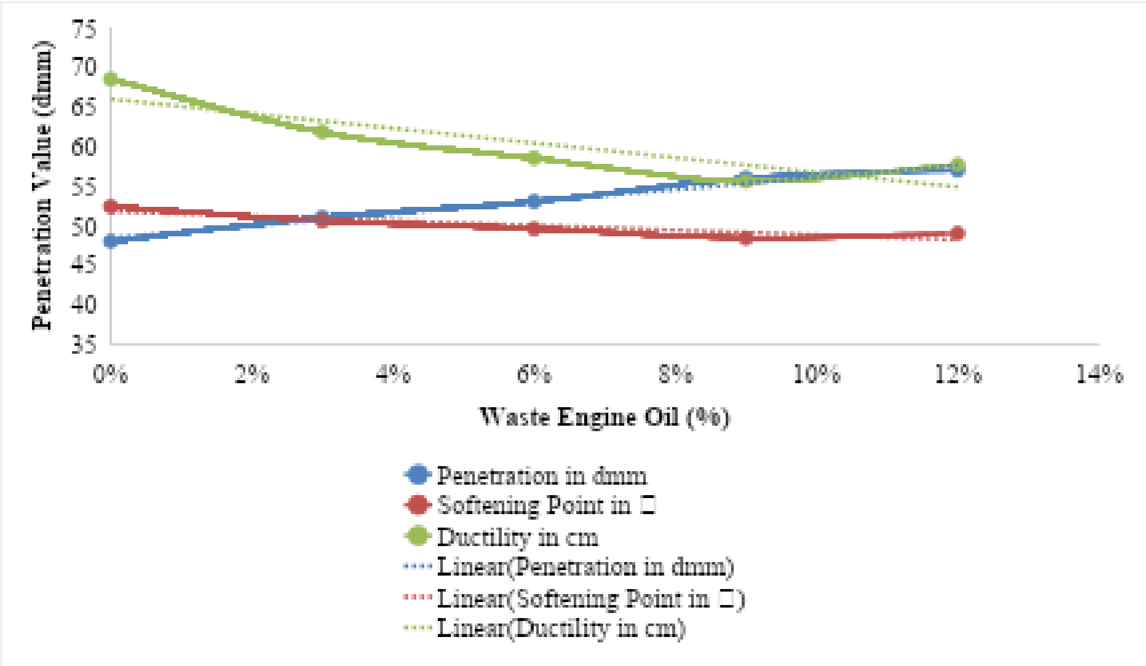
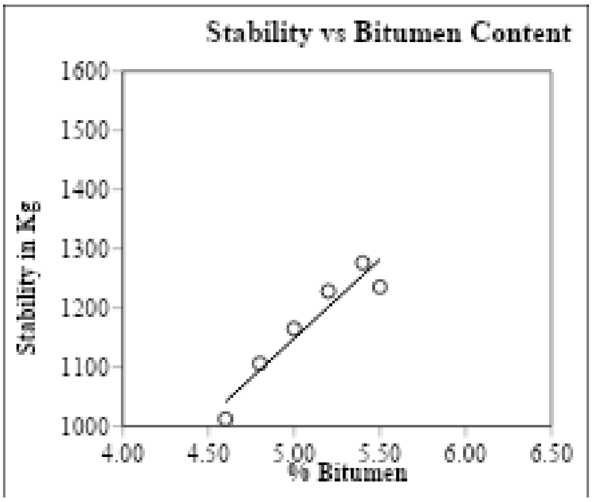


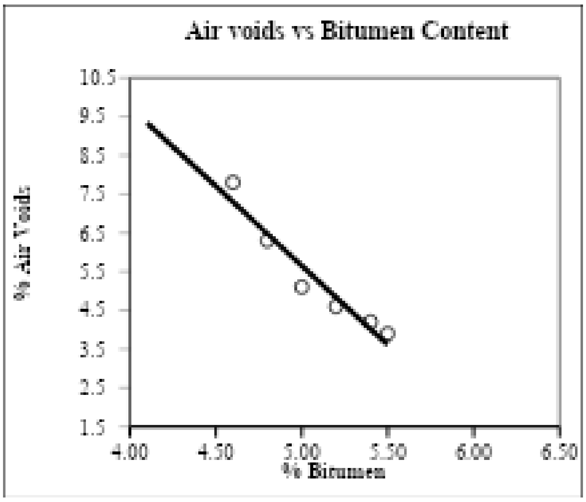
Figure 4.2 Penetration softening point and ductility values of bitumen modified withWaste Engine Oil

4.4 Marshall properties of VG- 30 Bitumen

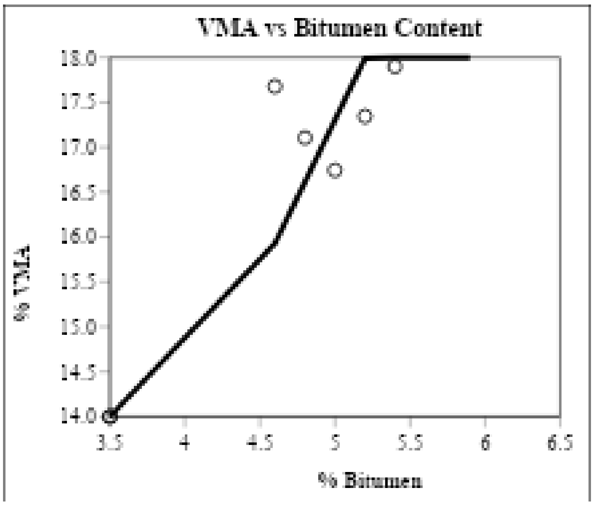
Table 4.3 presents the Marshall properties of plain VG 30 bitumen evaluated at varying bitumen contents ranging from 4.60% to 5.50%, with a focus on identifying the Optimum Bitumen Content (OBC) based on stability, density, and volumetric characteristics. The results indicate that as the bitumen content increases from 4.60% to 5.40%, key performance parameters such as density, stability, and Voids Filled with Bitumen (VFB) improve, reaching favorable levels at 5.40% presented in figure 4.3. The Void in Mix (VIM) and Voids in Mineral Aggregate (VMA) decrease slightly but remain within the acceptable range prescribed by MoRTH specifications.At 5.40%, the bitumen mix achieves its peak performance in terms of stability (1084 N) and balanced volumetric properties, making it the Optimum Bitumen Content for plain VG 30 binder. However, with a further increase to 5.50%, a decline is observed in density, stability, and flow values, suggesting the onset of over-binder conditions, which result in a softer mix with reduced load-bearing capacity and structural performance. The marginal increase in VMA and VFB beyond this point reflects excess binder occupying the air voids, leading to decreased internal friction among aggregates.This analysis confirms that for plain VG 30 bitumen, 5.40% is the most suitable binder content for achieving maximum strength and durability, while ensuring that the mix remains workable and compliant with design specifications.


Stability vs Bitumen Content
Stability in Kg
% Bitumen

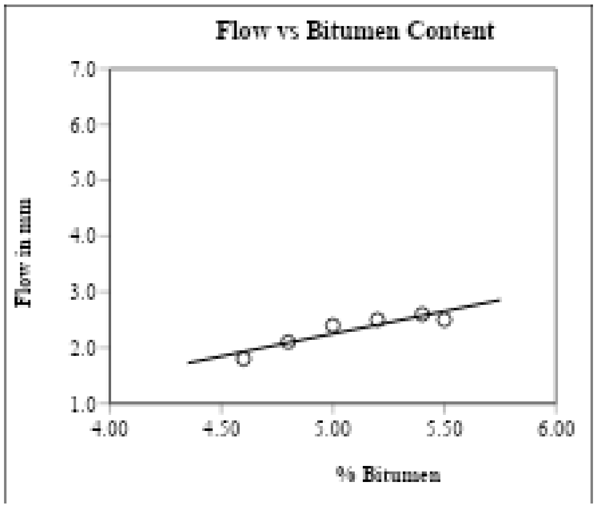
a)


Air voids vs Bitumen Content
% Air Voids
% Bitumen

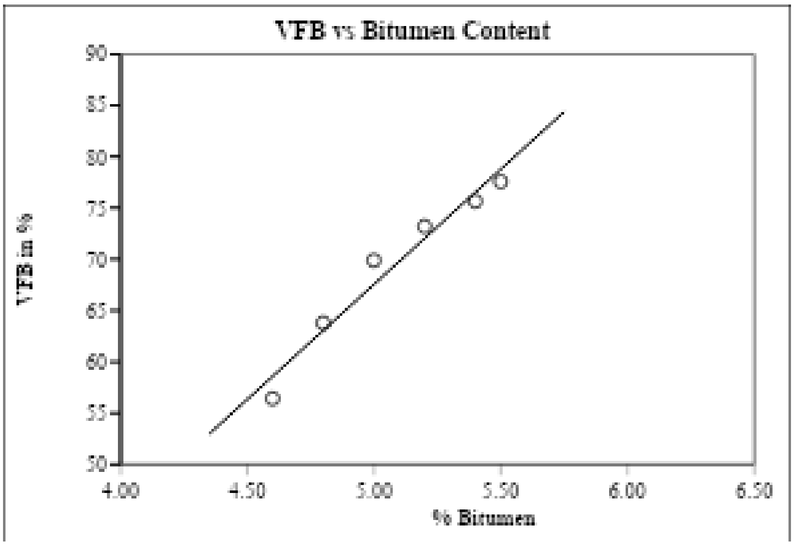
b)


VMA vs Bitumen Content
% VMA
% Bitumen

c)


Flow vs Bitumen Content
Flow in mm
% Bitumen

d)


VFB vs Bitumen Content
VFB in %
% Bitumen

e)

Figure 4.3 Marshall results for vg 30 bitumen a) Stability vs Bitumen Content b) Air voids vs Bitumen Content c) VMA vs Bitumen Content d) Flow vs Bitumen Content e) VFB vs Bitumen Content

Table 4.3 Marshall Properties of VG – 30 unmodified bitumen

Bitumen Content (%)	**Density (g/cc)**	**VIM (%)**	**VMA (%)**	**VFB (%)**	**Stability (N)**	**Flow (mm)**
4.60	2.490	7.8	17.90	56.42	1012	1.8
4.80	2.505	6.3	17.40	63.79	1106	2.1
5.00	2.520	5.1	16.95	69.89	1165	2.4
5.20	2.530	4.6	17.10	73.20	1228	2.5
5.40	**2.538**	**4.2**	**17.25**	**75.65**	**1276**	**2.6**
5.50	2.525	3.9	17.38	77.56	1235	2.5

4.5 Marshall properties of Bitumen modified with Surgical Gloves

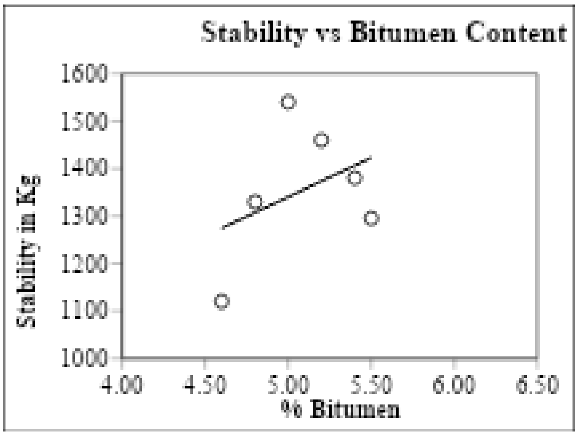
Table 4.4 presents the results of Marshall mix design tests conducted with varying percentages (3%, 6%, 9%, and 12%) of surgical glove modifier. Among these, 9% modifier content is identified as the optimal dose based on superior performance metrics.As the modifier content increases from 3% to 9%, there is a consistent improvement in the mix's performance. The **stability value**, a key indicator of resistance to deformation, increases significantly from **1250 kg at 3%** to a peak of **1540 kg at 9%**, demonstrating enhanced load-bearing capacity due to improved binder-aggregate interaction and mix cohesion. Beyond 9%, at **12%**, the stability value drops to **1320 kg**, indicating that over-modification may lead to reduced structural integrity, possibly due to excess rubber content affecting compaction and stiffness balance.Similarly, **Optimum Bitumen Content (OBC)** reduces slightly from **5.2% at 3% modifier** to **5.0% at 9%**, suggesting better binder utilization at the optimal dose. **Density** increases with modifier content up to 9%, indicating improved compaction, before slightly decreasing at 12%. **Voids in Mineral Aggregate (VMA)** and **Voids Filled with Bitumen (VFB)** values are also optimal at 9%, showing good volumetric balance. **Air voids (VIM)** decrease with increasing modifier content, reaching a desirable 4.5% at 9%, which aligns with recommended limits for durable pavement. **Flow values**, which represent the deformation before failure, remain within acceptable limits across all percentages, with a slightly increasing trend as the modifier percentage rises.Overall, the data clearly supports **9% surgical glove content** as the optimal level for modification, providing the best combination of strength, workability, and volumetric properties in the bituminous mix.

Table 4. 3 Marshall stability values for surgical gloves modified bitumen at different percentages

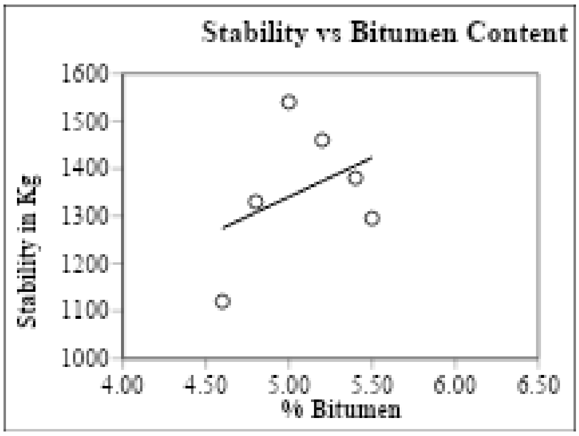
Modifier Content (%)	**OBC (%)**	**Density (g/cc)**	**VIM (%)**	**VMA (%)**	**VFB (%)**	**Stability (kg)**	**Flow (mm)**
3	5.2	2.488	5.2	17.40	70.11	1250	2.6
6	5.1	2.515	4.8	17.00	71.76	1395	2.7
9	5.0	2.548	4.5	16.74	73.06	1540	2.8
12	5.3	2.530	3.9	17.60	77.84	1320	3.0

Figure 4.4 presents the Marshall properties of VG 30 bitumen modified with 9% shredded surgical gloves content by weight of bitumen. The objective of this modification was to evaluate its influence on key parameters such as stability, flow, density, and volumetric characteristics to determine the Optimum Bitumen Content (OBC). The Marshall Stability values show a significant improvement with increasing bitumen content, peaking at 1540 N at 5.00% bitumen, which is identified as the OBC for this modified mix. This increase in stability compared to unmodified bitumen indicates enhanced resistance to deformation and better load-bearing capacity, likely due to the elastic and polymeric nature of the glove material improving the binding performance and stiffness of the mix.Other parameters also followed expected trends: density increased up to 5.00% and slightly declined thereafter, while Voids in Mineral Aggregate (VMA) and Voids Filled with Bitumen (VFB) showed consistent improvement, confirming better compaction and binder coating. The flow values remained within permissible limits, suggesting that the mix retained adequate flexibility without becoming overly stiff. These results confirm that the incorporation of 9% surgical

gloves into VG 30 bitumen not only enhances its mechanical performance but also supports sustainability through plastic waste reuse in road construction.



a)



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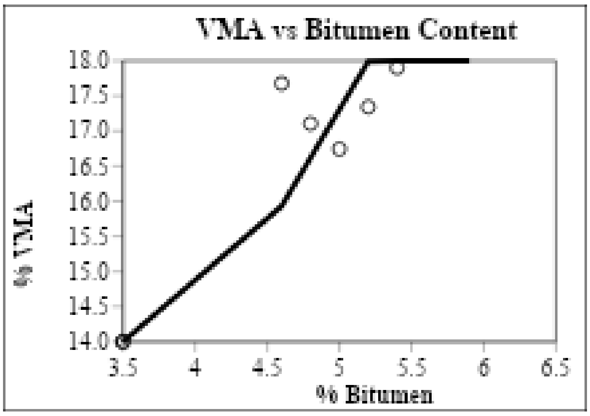
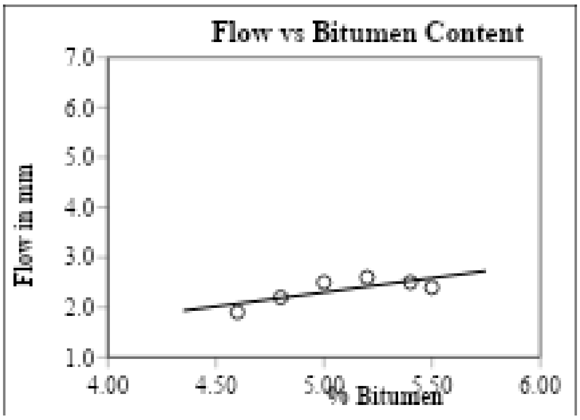


c)



d)

(e)

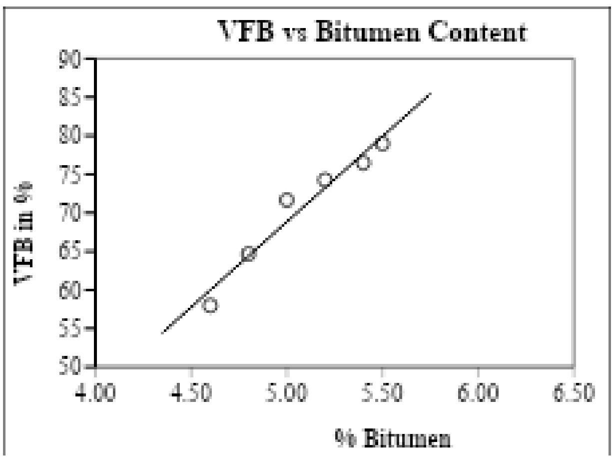


Figure 4.4 Marshall stability test results for 9% surgical gloves content (a) Stability vs Bitumen Content (b) Air voids vs Bitumen Content (c) VMA vs Bitumen Content (d) Flow vs Bitumen Content (e) VFB vs Bitumen Content

4.6 Marshall Properties of Bitumen modified with Waste Engine Oil

The table titled *"Table 4.5 Marshall stability values for waste engine oil modified bitumen at different percentages"* presents the effect of varying waste engine oil (WEO) contents—3%, 6%, 9%, and 12%—on the Marshall properties of bituminous mixes. The key parameters evaluated include Optimum Bitumen Content (OBC), density, air voids (VIM), voids in mineral aggregate (VMA), voids filled with bitumen (VFB), Marshall stability, and flow. These values help assess the suitability and effectiveness of WEO as a bitumen modifier.As the modifier content increases from 3% to 9%, there is a noticeable improvement in mix performance. The density rises steadily, peaking at 2.540 g/cc at 9%, indicating enhanced compaction and material bonding. Similarly, the air voids (VIM) decrease from 5.0% to 4.5%, which aligns with the optimal range for pavement durability. VMA values show a slight decline, reaching 16.74% at 9%, while VFB improves, peaking at 73.06%, suggesting more efficient void filling and better binder distribution within the mix.The most significant improvement is observed in the Marshall Stability, which increases from 1178 kg at 3% to a maximum of 1265 kg at 9%, demonstrating enhanced resistance to deformation and better structural strength due to optimal modification. However, at 12% WEO content, the stability drops to 1140 kg, and the flow increases to 3.0 mm, indicating over-modification. This may lead to excessive binder softening, reduced stiffness, and higher susceptibility to rutting.Overall, the data shows that 9% WEO content offers the most balanced and optimal performance across all parameters, with the highest stability, desirable air voids, and proper volumetric characteristics. Increasing the modifier content beyond this point leads to diminishing returns, confirming 9% as the ideal dosage for WEO-modified bitumen in this study.

Table 4. 4 Marshall stability values for waste engine oil modified bitumen at different percentages

Modifier Content (%)	**OBC (%)**	**Density (g/cc)**	**VIM (%)**	**VMA (%)**	**VFB (%)**	**Stability (kg)**	**Flow (mm)**
3	5.2	2.490	5.0	17.20	70.93	1178	2.6
6	5.1	2.510	4.8	16.90	71.60	1220	2.7
9	5.0	2.540	4.5	16.74	73.06	1265	2.8
12	5.3	2.520	3.8	17.60	78.41	1140	3.0

Summary

This chapter gave result of experimental works on the effect of surgical gloves and waste engine oil effects on bitumen at different percentages. The focus of this assessment was on the Marshall mix design parameters and intrinsic physical properties so as to determine the effects of waste-based modifiers on the performance of bituminous mixes. Results revealed that both the modifiers highly influenced the behaviour of bitumen. For surgical gloves, 9% modifier content was found to be the optimum dosage as it has given the highest Marshall stability (1540 kg), desirable air void and balanced volumetric properties which reveals better load-bearing capability and durability on the mix. In the same fashion, the 9% variation produced the best results when it comes to strength and workability for the waste engine oil and the stability was also high of 1265 kg and good volumetric properties. As in the case of binder properties, greater percentage of the modifiers brought a higher value of penetration as well as a lower softening point which is an indication of softening effect on bitumen. Ductility decrease with increasing amount of modifier, an indication of variation in elasticity and cohesive strength. Specific gravity, flash point and fire point decreased slightly pointing to the effect of lower and more volatile items in the modifiers. Overall, the introduction of surgical gloves and waste engine oil as modifiers has demonstrated a potential in improving some of the properties of bituminous mixes, towards sustainable use of waste materials. The results obtained in this chapter can be used as a strong basis for finalising the research and suggesting optimal dosages of modifiers for implementation purposes.

CHAPTER 5

CONCLUSION

This study was aimed at understanding the influence of enriching the bitumen with waste engine oil (WEO) and surgical gloves as modifiers on both physical property of the binder and the Marshall of bituminous mixes. From the findings, it is evident that both modifiers significantly alter the performance characteristics of bitumen at varying trends in their behavior from 3%, 6%, 9% and 12%.

1. Waste Engine Oil-Impact of on the Bitumen properties:

The results showed that the inclusion of WEO increases penetration value of 48 dmm (unmodified) to 57 dmm at 12% which is seen as softening of bitumen. This is further influenced by a reduction in Softening point which is reduced to 48.4°C from 52.4°C at 9% before mildly increasing in indicating-decrease fractional resistance to the deformation of high temperatures. Just the same, ductility was also found to decline with increasing WEO content, indicating reduction in the binder's elongation ability without breaking, which can translate into fatigue resistance. Specific gravity reduced marginally (lighter in WEO), whilst flash and fire points suffered minor reductions (within the safety limits of safe handling).

2. Effect of Waste Engine Oil on Marshall Properties:

Marshall mix design results for WEO-modified mixes showed improvement in mix behavior up to 9% WEO content. The Marshall stability increased from 1178 kg at 3% to a maximum of 1265 kg at 9%, reflecting enhanced load-bearing capacity. However, a decline was observed at 12%, suggesting over-modification that might cause binder drainage or mix softening. Voids in mineral aggregate (VMA) and voids filled with bitumen (VFB) were within acceptable ranges, while air voids (VIM) gradually decreased, improving mix compaction. Flow values remained within the permissible limits, confirming the workability and flexibility of the mixes.

3. Effect of Surgical Glove Modification on Marshall Properties:

The surgical glove-modified mixes exhibited significant improvements in structural performance. The Marshall stability peaked at 1540 kg for 9% modifier content, the highest among all tested mixes. This indicates superior binder-aggregate bonding and improved stiffness. At 9% dosage, optimal values were also achieved for density (2.548 g/cc), VIM (4.5%), VMA (16.74%), and VFB (73.06%), all of which align with ideal volumetric conditions for a durable pavement mix. Beyond 9%, however, a decline in stability and an increase in flow suggest that higher concentrations of surgical glove material could negatively impact the balance between strength and flexibility.

4. Comparative Evaluation and Optimum Dosage:

Between the two waste modifiers, surgical gloves provided better performance in terms of strength and stability, while WEO enhanced workability and compaction by softening the mix. In both cases, the 9% modifier content emerged as the optimum dose, offering the best balance between strength, durability, and volumetric compliance. The trend observed in the data confirms that moderate inclusion of waste materials can enhance bituminous mix performance, but overuse may lead to degradation in properties.

5. Environmental and Practical Implications:

The utilization of waste engine oil and surgical gloves does not only enhance the performance of pavements but also advances sustainable construction practices through recycling of waste and saving the resources used. Use of non-degradable solid wastes and other environmentally damaging wastes materials into construction of road can significantly reduce the environmental footprint of infrastructure development without increasing reliance on virgin materials.The study concludes both waste engine oil and surgical gloves as viable and effective bitumen modifiers. One of them was surgical gloves that delivered better performance in regards to Marshall stability and mix strength and was therefore highly indicated for the tasks characterized by high structural quality. Waste engine oil on the other hand has its merits when it comes to flexibility and compacting capability, whereby it is appropriate for locations that require flexibility. All in all, 9% modifier content is suggested as the optimal for both the modifiers. These results highlight the strength of using industrial and medical waste to strengthen flexible pavement, congruent with the engineering performance and the pursuit for environmental sustainability.

Future Scope:

- Further investigation can be conducted on the long-term aging effects of modified bitumen using simulated aging tests such as RTFO and PAV.
- Field performance studies and pavement trials can be undertaken to validate laboratory results under real traffic and environmental conditions.
- Micro structural and chemical analysis using techniques like FTIR, SEM, and TGA can help understand the interaction mechanism between waste modifiers and bitumen.
- The impact of modifiers on moisture susceptibility and stripping resistance can be explored using tests like the tensile strength ratio (TSR).

- Studies can be extended to evaluate the rutting and fatigue behavior using advanced tests such as Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR).
- The potential for combined use of multiple waste materials (e.g., gloves + WEO or with fibers/fillers) can be explored for synergistic effects.

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