DESIGN AND PERFORMANCE EVALUATION OF PLASTIC AND RUBBER MODIFIED BITUMINOUS PAVEMENT

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ABSTRACT

The increasing demand for sustainable road construction and the rapid accumulation of plastic and rubber waste have become major environmental challenges worldwide. Conventional bituminous pavements require large quantities of natural materials and petroleum-based binders, resulting in increased construction costs and environmental concerns. The utilization of waste plastic and waste rubber as modifiers in bitumen offers an effective solution for improving pavement performance while simultaneously addressing waste disposal problems. Plastic and rubber modified bitumen enhances the engineering properties of conventional bitumen by increasing its stability, flexibility, resistance to deformation, and durability under varying traffic and climatic conditions. This project presents the Design of Bitumen Modified with Plastic/Rubber Road by investigating the suitability of waste plastic and crumb rubber as bitumen modifiers for flexible pavement construction. The study focuses on evaluating the physical and mechanical properties of modified bitumen using laboratory tests such as penetration test, softening point test, ductility test, viscosity test, specific gravity test, and Marshall Stability test. Different percentages of waste plastic and crumb rubber are blended with conventional bitumen to determine the optimum modifier content that provides maximum pavement performance. The experimental results demonstrate that plastic/rubber modified bitumen significantly improves Marshall Stability, load-bearing capacity, rutting resistance, fatigue resistance, moisture resistance, and service life compared with conventional bitumen. The modified pavement also exhibits lower maintenance requirements and improved resistance to high-temperature deformation and cracking. The proposed methodology provides highway engineers with an economical and environmentally sustainable approach for road construction by converting waste plastic and rubber materials into valuable pavement resources while reducing environmental pollution and improving the durability of flexible pavements.

Keywords : Plastic Modified Bitumen, Rubber Modified Bitumen, Waste Plastic, Crumb Rubber, Marshall Stability, Flexible Pavement, Sustainable Road Construction, Bituminous Mix, Highway Engineering, Pavement Performance, Recycling Technology, Green Roads.

I. INTRODUCTION

Road transportation is one of the most important components of modern infrastructure, contributing significantly to economic development, industrial growth, and regional connectivity. The continuous increase in traffic volume and axle loads has created a growing demand for durable, economical, and sustainable pavement construction materials. Conventional bituminous pavements are widely used because of their flexibility, ease of construction, and relatively low initial cost. However, prolonged exposure to heavy traffic and varying climatic conditions often results in pavement failures such as rutting, potholes, fatigue cracking, bleeding, and permanent deformation. At the same time, the accumulation of plastic and rubber waste has become a major environmental concern due to improper disposal and the non-biodegradable nature of these materials. Recycling waste plastic and rubber in road construction has emerged as an effective solution for reducing environmental pollution while improving pavement performance. The incorporation of waste plastic and crumb rubber into bitumen enhances its physical and mechanical properties, increases pavement durability, and minimizes maintenance requirements. Consequently, plastic/rubber modified bitumen has gained significant attention as a sustainable alternative to conventional road construction materials.

Recent advancements in highway engineering have focused on improving the engineering characteristics of bitumen through the incorporation of waste materials. Plastic modified bitumen and rubber modified bitumen exhibit superior resistance to moisture damage, rutting, fatigue cracking, and temperature-induced deformation compared with conventional bitumen. The modification process involves blending shredded waste plastic and crumb rubber with heated bitumen to produce a homogeneous binder with improved strength and elasticity. Researchers have demonstrated that modified bitumen possesses higher Marshall Stability, increased softening point, improved viscosity, and enhanced binding characteristics, resulting in longer pavement service life. Various laboratory tests such as the penetration test, ductility test, softening point test, viscosity test, specific gravity test, and Marshall Stability test are commonly performed to evaluate the quality and performance of modified bituminous mixtures. The adoption of plastic and rubber modified roads also contributes to sustainable waste management by converting discarded plastic bags, bottles, tyres, and other polymer-based materials into valuable construction resources.

This project presents the Design of Bitumen Modified with Plastic/Rubber Road by investigating the suitability of waste plastic and crumb rubber as modifiers for conventional bitumen in flexible pavement construction. The study aims to evaluate the physical, mechanical, and durability characteristics of plastic/rubber modified bitumen using standard laboratory testing procedures. Various percentages of waste plastic and crumb rubber are incorporated into conventional bitumen to determine the optimum modifier content capable of providing maximum pavement performance. Laboratory investigations include the penetration test, softening point test, ductility test, viscosity test, specific gravity test, and Marshall Stability test to compare the properties of conventional and modified bitumen. The experimental results are analysed to determine improvements in stability, load-carrying capacity, moisture resistance, fatigue resistance, and rutting resistance. The study demonstrates that the use of plastic and rubber modified bitumen significantly enhances pavement performance while simultaneously reducing plastic and rubber waste disposal problems. The proposed methodology provides an economical, environmentally friendly, and sustainable solution for modern highway construction by improving pavement durability, reducing maintenance costs, conserving natural resources, and promoting the recycling of non-biodegradable waste materials.

II. SURVEY OF RESEARCH

1. Plastic and Rubber Modified Bitumen in Highway Engineering

The increasing generation of plastic and rubber waste has encouraged researchers to investigate their utilization in road construction as sustainable pavement materials. Conventional bitumen exhibits limitations such as low resistance to rutting, fatigue cracking, and temperature variations, which reduce pavement durability under heavy traffic conditions. Several studies have demonstrated that incorporating waste plastic and crumb rubber into bitumen significantly improves the engineering properties of asphalt mixtures. Plastic and rubber modified bitumen enhances flexibility, elasticity, adhesion, and resistance to moisture damage while reducing permanent deformation and thermal cracking. Researchers have reported that modified pavements possess longer service life, improved load-bearing capacity, and lower maintenance costs compared with conventional pavements. In addition to improving pavement performance, the reuse of plastic and rubber waste contributes to environmental sustainability by reducing landfill disposal and promoting recycling. These findings highlight the importance of polymer-modified bitumen as an economical and eco-friendly solution for modern highway construction.

2. Marshall Stability Analysis of Modified Bitumen

Marshall Stability testing is one of the most widely adopted laboratory methods for evaluating the strength and performance of bituminous mixtures. Researchers have extensively used this method to determine the optimum percentage of plastic and rubber modifiers in bitumen. The test measures the maximum load that a bituminous specimen can withstand before failure and evaluates the corresponding flow value. Studies indicate that the addition of waste plastic and crumb rubber increases Marshall Stability while maintaining acceptable flow characteristics. Improved stability reflects enhanced resistance to permanent deformation and rutting under heavy traffic loading. Researchers have also observed that modified bituminous mixtures exhibit better aggregate binding, higher density, and improved structural integrity compared with conventional mixtures. Consequently, Marshall Stability analysis has become an essential tool for optimizing bitumen modification and ensuring the durability of flexible pavements.

3. Mechanical Properties of Plastic/Rubber Modified Bitumen

Several laboratory investigations have focused on evaluating the mechanical properties of plastic and rubber modified bitumen. Common laboratory tests include the penetration test, softening point test, ductility test, viscosity test, specific gravity test, and Marshall Stability test. Research findings indicate that modified bitumen generally exhibits lower penetration values, indicating increased hardness and improved resistance to rutting. The softening point increases due to enhanced thermal stability, allowing the pavement to perform better under high-temperature conditions. Although ductility decreases slightly with increasing plastic or rubber content, the values remain within acceptable engineering limits for pavement construction. Modified bitumen also demonstrates higher viscosity, which improves aggregate coating and bonding characteristics. These improvements contribute to increased pavement strength, reduced moisture susceptibility, enhanced fatigue resistance, and longer service life.

4. Environmental Benefits of Plastic and Rubber Waste Utilization

The disposal of plastic and rubber waste has become a major environmental challenge due to the non-biodegradable nature of these materials. Researchers have proposed road construction as an effective method for recycling plastic bags, bottles, packaging materials, and discarded vehicle tyres. Experimental studies have shown that incorporating waste plastic and crumb rubber into bituminous mixtures significantly reduces environmental pollution while conserving natural resources. The recycling process decreases the quantity of waste disposed in landfills and minimizes the environmental impact associated with conventional waste management practices. Additionally, reduced consumption of virgin bitumen lowers the demand for petroleum-based materials, contributing to sustainable infrastructure development. Comparative studies have confirmed that plastic/rubber modified roads provide both environmental and economic advantages while maintaining high structural performance and long-term pavement durability.

5. Performance Evaluation of Plastic/Rubber Modified Roads

Performance evaluation plays an important role in determining the suitability of modified bituminous mixtures for highway construction. Researchers have analysed modified pavements using parameters such as Marshall Stability, flow value, air voids, bulk density, voids filled with bitumen (VFB), rutting resistance, fatigue resistance, and moisture susceptibility. Experimental investigations indicate that pavements constructed using plastic/rubber modified bitumen exhibit improved resistance to heavy axle loads, reduced permanent deformation, and enhanced structural stability. The modified binder improves adhesion between aggregates and bitumen, thereby minimizing stripping and moisture damage. Comparative analyses have demonstrated that modified pavements require less maintenance and exhibit superior performance throughout their service life compared with conventional bituminous roads. These findings support the large-scale implementation of polymer-modified bitumen in modern highway engineering projects.

6. Future Trends in Sustainable Bituminous Pavement Technology

Recent developments in pavement engineering focus on integrating recycled polymers, waste tyres, nanomaterials, warm mix asphalt technology, Artificial Intelligence (AI), and Machine Learning (ML) into pavement design and quality control. Researchers are developing intelligent pavement management systems capable of predicting pavement deterioration based on traffic loading, environmental conditions, and material properties. Advanced laboratory testing and numerical simulations are being combined with AI algorithms to optimize bitumen modification and pavement performance. Smart sensors embedded within road pavements enable continuous monitoring of temperature, strain, moisture, and traffic loading, facilitating preventive maintenance and extending pavement service life. Future research is expected to integrate sustainable materials, digital monitoring systems, and advanced computational techniques to develop environmentally friendly, durable, and high-performance roads capable of meeting future transportation demands while minimizing environmental impact.

III. PROPOSED SYSTEM

The proposed Design of Bitumen Modified with Plastic/Rubber Road aims to develop a sustainable, durable, and economical flexible pavement by utilizing waste plastic and crumb rubber as modifiers in conventional bitumen. The proposed system integrates waste material collection, material characterization, bitumen modification, laboratory testing, mix design, pavement performance evaluation, and optimization to produce a high-performance bituminous mix suitable for modern highway construction. The methodology follows the relevant provisions of the Ministry of Road Transport and Highways (MoRTH) specifications and IRC guidelines for bituminous pavement construction. The primary objective is to improve pavement strength, durability, moisture resistance, and fatigue performance while simultaneously reducing environmental pollution caused by plastic and rubber waste. Initially, waste plastic materials such as carry bags, plastic bottles, packaging films, disposable cups, and polyethylene products along with crumb rubber obtained from discarded vehicle tyres are collected from municipal waste and recycling centres. The collected materials are cleaned thoroughly to remove dust, moisture, and other contaminants before processing. Plastic waste is shredded into small pieces of approximately 2–4 mm, while waste tyres are processed into fine crumb rubber particles using mechanical shredding equipment. Simultaneously, conventional paving-grade bitumen and aggregates are tested to determine their physical and engineering properties such as penetration value, softening point, ductility, specific gravity, aggregate impact value, crushing value, and water absorption. These preliminary investigations ensure that all materials satisfy the standard quality requirements for road construction.

After material characterization, the bitumen modification process is carried out using the dry process or wet process depending on the selected experimental procedure. In the dry process, shredded plastic and crumb rubber are mixed with heated aggregates before adding hot bitumen, whereas in the wet process the modifiers are blended directly with molten bitumen at controlled temperatures to produce a homogeneous modified binder. Different percentages of waste plastic and crumb rubber are incorporated into conventional bitumen to determine the optimum modifier content. The modified binder is continuously stirred to achieve uniform dispersion of the polymer materials and improve adhesion between bitumen and aggregates. The prepared modified mix is then used for preparing laboratory specimens for performance evaluation. The prepared specimens are subjected to various laboratory tests to evaluate the physical and mechanical properties of the modified bituminous mixture. Important laboratory investigations include the penetration test, softening point test, ductility test, viscosity test, specific gravity test, and Marshall Stability test. The penetration test evaluates the hardness of the modified bitumen, while the softening point determines its resistance to high-temperature deformation. The ductility test measures the flexibility of the binder, and the viscosity test evaluates the workability of the modified bitumen during mixing and compaction. The Marshall Stability test is performed to determine the maximum load-carrying capacity and flow characteristics of the bituminous mixture. The obtained results are compared with those of conventional bitumen to assess the effectiveness of plastic and rubber modification.

Following laboratory testing, the performance of the modified pavement is analysed by comparing important engineering parameters including Marshall Stability, flow value, air voids, bulk density, voids filled with bitumen (VFB), moisture resistance, rutting resistance, fatigue resistance, and temperature susceptibility. If the obtained results do not satisfy the required design specifications, the percentage of plastic and rubber modifiers is adjusted and the laboratory testing is repeated until the optimum mix proportion is obtained. This iterative optimization process ensures maximum structural performance while maintaining economical material usage and compliance with highway engineering standards. Finally, the effectiveness of the proposed system is evaluated using the optimum modified bituminous mixture obtained through experimental investigation. The comparative analysis demonstrates significant improvements in Marshall Stability, load-bearing capacity, fatigue resistance, rutting resistance, water resistance, and thermal stability compared with conventional bitumen. The incorporation of waste plastic and crumb rubber also reduces the consumption of virgin bitumen, minimizes environmental pollution, promotes sustainable waste management, and extends pavement service life. The proposed methodology therefore provides highway engineers with an efficient, environmentally friendly, and economically viable solution for constructing durable flexible pavements using recycled waste materials while supporting sustainable infrastructure development.

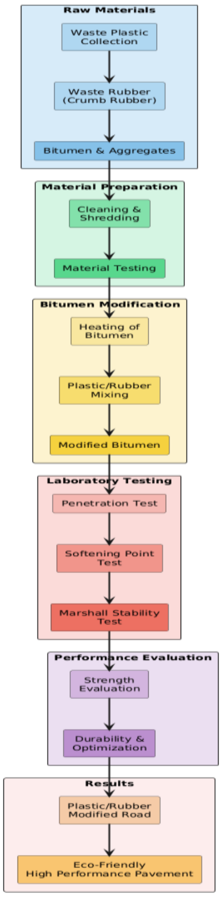

Fig1: Proposed workflow

III. WORKING METHODOLOGY

The proposed Design of Bitumen Modified with Plastic/Rubber Road follows a systematic methodology to develop a durable, economical, and environmentally sustainable bituminous pavement using waste plastic and crumb rubber as bitumen modifiers. The methodology consists of waste material collection, material preparation, bitumen modification, laboratory testing, mix design optimization, pavement performance evaluation, and quality assessment. The complete process is carried out according to the specifications of the Indian Roads Congress (IRC) and the Ministry of Road Transport and Highways (MoRTH) to ensure that the modified pavement satisfies the required engineering and performance standards.

Initially, waste plastic materials such as polyethylene carry bags, plastic bottles, food packaging materials, disposable cups, and plastic wrappers are collected from municipal solid waste and recycling centres. Simultaneously, discarded automobile tyres are processed to obtain crumb rubber through shredding and grinding operations. The collected plastic and rubber materials are cleaned thoroughly to remove dirt, moisture, paper, and other impurities before processing. The plastic waste is shredded into small pieces of approximately 2–4 mm, while the rubber is converted into uniformly graded crumb rubber particles. Conventional paving-grade bitumen and aggregates are also tested for their physical properties, including penetration value, specific gravity, crushing value, impact value, abrasion value, and water absorption. These preliminary investigations ensure that all materials satisfy the quality requirements for highway construction.

After preparing the raw materials, the bitumen modification process is carried out using either the dry process or the wet process. In the dry process, heated aggregates are first coated with shredded plastic before the addition of hot bitumen and crumb rubber. In the wet process, crumb rubber and shredded plastic are blended directly with heated bitumen at controlled temperatures ranging between 160°C and 180°C to produce a homogeneous modified binder. Continuous stirring is maintained to ensure uniform distribution of polymer particles throughout the bitumen. Different percentages of plastic and rubber are incorporated into the binder to determine the optimum modifier content capable of providing maximum pavement performance. The prepared modified binder exhibits improved adhesion, elasticity, viscosity, and resistance to temperature variations compared with conventional bitumen.

The modified bituminous mix is then prepared by combining the modified binder with properly graded aggregates according to the selected mix design. The mixture is heated, mixed, and compacted using standard laboratory procedures to prepare cylindrical Marshall specimens. The prepared specimens are subjected to a series of laboratory investigations including the penetration test, softening point test, ductility test, viscosity test, specific gravity test, and Marshall Stability test. These tests evaluate the engineering characteristics of the modified binder and determine its suitability for flexible pavement construction. The penetration test measures the hardness of bitumen, the softening point test evaluates thermal resistance, the ductility test measures flexibility, and the Marshall Stability test determines the load-bearing capacity and deformation characteristics of the modified bituminous mixture.

Following laboratory testing, the experimental results are analysed to evaluate the structural performance of the modified pavement. Important engineering parameters including Marshall Stability, flow value, bulk density, air voids, voids in mineral aggregate (VMA), voids filled with bitumen (VFB), moisture resistance, rutting resistance, fatigue resistance, and temperature susceptibility are determined. The obtained values are compared with those of conventional bituminous mixtures as well as the permissible limits specified by IRC standards. If any parameter does not satisfy the design requirements, the percentage of plastic and rubber modifiers is adjusted and the laboratory testing is repeated until the optimum mix proportion is achieved. This iterative optimization process ensures maximum pavement strength while minimizing material consumption and construction cost.

Finally, the optimized plastic/rubber modified bituminous mix is evaluated for its long-term structural performance under simulated traffic and environmental conditions. Comparative analysis is carried out to assess improvements in load-bearing capacity, fatigue life, rutting resistance, water resistance, thermal stability, service life, and overall pavement durability. The incorporation of waste plastic and crumb rubber significantly improves the engineering performance of the pavement while reducing the consumption of virgin bitumen. In addition to enhancing pavement quality, the proposed methodology contributes to sustainable waste management by recycling non-biodegradable plastic and rubber waste into valuable highway construction materials. The developed framework therefore provides highway engineers with an economical, environmentally friendly, and technically reliable approach for constructing high-performance flexible pavements with improved durability and reduced maintenance requirements.

Engineering Formulae

Equation (1): Marshall Stability

$$MS = P_{max}$$

Equation (2): Bulk Density

$$\rho = \frac{W}{V}$$

Equation (3): Air Voids

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) \times 100$$

Equation (4): Voids in Mineral Aggregate (VMA)

$$VMA = 100 - \frac{G_{mb}(1 - P_b)}{G_{sb}} \times 100$$

Equation (5): Voids Filled with Bitumen (VFB)

$$VFB = \frac{VMA - V_a}{VMA} \times 100$$

These equations are commonly used in the design and evaluation of plastic/rubber modified bituminous pavements and are consistent with IRC and MoRTH practices for Marshall Mix Design and bituminous road construction.

V. IMPLEMENTATION

The implementation of the proposed Design of Bitumen Modified with Plastic/Rubber Road was carried out to investigate the effectiveness of incorporating waste plastic and crumb rubber into conventional bitumen for flexible pavement construction. The implementation consisted of waste material collection, material preparation, bitumen modification, specimen preparation, laboratory testing, performance evaluation, and optimization of the modified mix. The complete experimental procedure was conducted according to the guidelines of the Indian Roads Congress (IRC) and the Ministry of Road Transport and Highways (MoRTH) to ensure the quality and suitability of the modified pavement for highway applications.

Initially, waste plastic materials including polyethylene carry bags, plastic bottles, packaging films, disposable cups, and food wrappers were collected from municipal solid waste collection centres and recycling units. Waste automobile tyres were processed separately to obtain crumb rubber through mechanical shredding and grinding operations. The collected plastic and rubber materials were washed thoroughly to remove dust, moisture, and foreign particles before processing. Plastic waste was shredded into pieces of approximately 2–4 mm, while crumb rubber was sieved to obtain uniformly graded particles suitable for bitumen modification. Simultaneously, conventional paving-grade bitumen and aggregates were tested for important engineering properties such as penetration value, softening point, specific gravity, aggregate impact value, crushing value, abrasion value, and water absorption to ensure compliance with standard specifications.

After material preparation, the modified bitumen was produced using the dry process. Aggregates were heated to approximately 170°C, and shredded plastic was gradually added while continuously mixing to obtain a uniform plastic coating over the aggregate surface. Subsequently, paving-grade bitumen heated to approximately 160°C was added, followed by the addition of crumb rubber in predetermined proportions. Continuous stirring was maintained throughout the mixing process to ensure homogeneous dispersion of the modifiers and proper coating of aggregates. Different percentages of plastic and crumb rubber were prepared to identify the optimum modifier content capable of providing the highest pavement performance while maintaining good workability during construction.

The prepared modified bituminous mix was compacted into Marshall specimens using the standard Marshall compaction procedure. Cylindrical specimens were produced under controlled laboratory conditions and subjected to a comprehensive series of laboratory investigations including the penetration test, softening point test, ductility test, viscosity test, specific gravity test, and Marshall Stability test. These tests were performed to evaluate the physical and mechanical characteristics of the modified binder and compare its performance with conventional bitumen. The Marshall Stability test was used to determine the maximum load-bearing capacity and corresponding flow value of the modified mixture under compressive loading.

The experimental results obtained from laboratory testing were analysed to evaluate important engineering parameters such as Marshall Stability, flow value, bulk density, air voids, voids in mineral aggregate (VMA), voids filled with bitumen (VFB), moisture resistance, fatigue resistance, rutting resistance, and temperature susceptibility. The results were compared with conventional bituminous mixtures and the permissible values recommended by IRC specifications. If any performance parameter failed to satisfy the required limits, the percentage of waste plastic and crumb rubber was adjusted, and the experimental procedure was repeated until the optimum modified bitumen composition was achieved.

Finally, the optimized plastic/rubber modified bituminous mix was evaluated for its overall pavement performance under simulated traffic and environmental conditions. The modified pavement demonstrated higher Marshall Stability, improved aggregate bonding, greater rutting resistance, enhanced fatigue performance, superior moisture resistance, and better thermal stability than conventional bituminous pavements. The incorporation of recycled plastic and rubber significantly reduced the consumption of virgin bitumen while providing an environmentally sustainable solution for waste management. The implementation confirmed that plastic/rubber modified bitumen is an economical, durable, and eco-friendly alternative for the construction of high-performance flexible pavements with reduced maintenance requirements and extended service life.

VI. RESULTS EXPLANATIONS

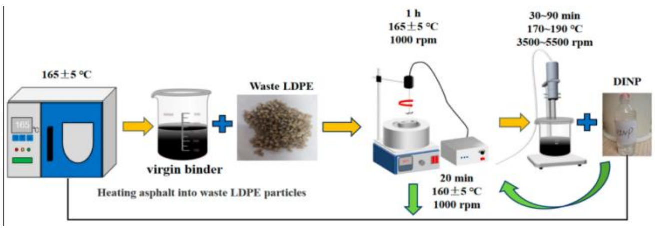

Figure 2. Collection and Processing of Plastic and Rubber Waste

Figure 2 illustrates the initial stage of the project, where waste plastic and discarded automobile tyres are collected and processed before being used in road construction. Plastic materials such as carry bags, bottles, food wrappers, and packaging films are cleaned and shredded into small particles of approximately 2–4 mm. Waste tyres are mechanically processed to produce uniformly graded crumb rubber. Proper cleaning and size reduction improve the mixing efficiency and ensure homogeneous distribution of modifiers within the bitumen. Recycling these waste materials significantly reduces environmental pollution while conserving natural resources. The processed plastic and crumb rubber exhibit suitable physical properties for blending with hot bitumen, thereby improving pavement durability and structural performance. This stage forms the foundation of the modified bitumen preparation process and supports sustainable highway construction through effective waste management and recycling.

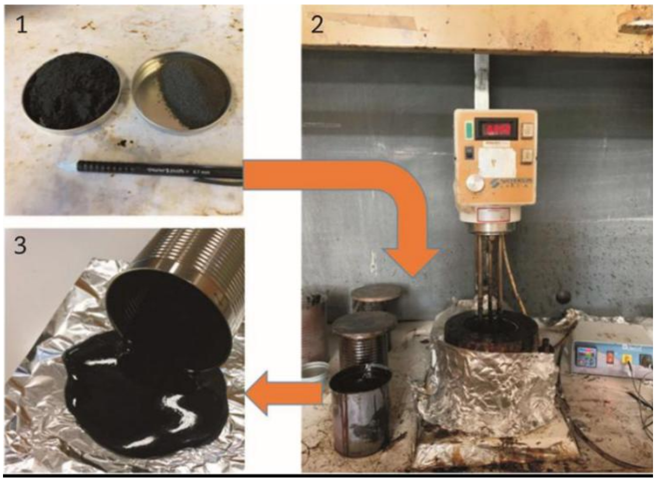

Figure 3. Preparation of Plastic/Rubber Modified Bitumen

Figure 3 presents the preparation of the modified bituminous binder using the dry mixing process. Aggregates are heated to the required temperature before shredded plastic is added to form a thin polymer coating over the aggregate surface. Subsequently, hot bitumen and crumb rubber are incorporated under continuous stirring to produce a homogeneous modified binder. Proper temperature control ensures uniform mixing without degrading the polymer materials. The modified binder demonstrates higher viscosity, improved elasticity, and stronger adhesion compared with conventional bitumen. These enhanced engineering properties improve aggregate bonding and reduce the likelihood of stripping, rutting, and fatigue cracking under traffic loading. The successful preparation of the modified binder confirms that waste plastic and crumb rubber can be effectively recycled into high-performance road construction materials while reducing dependence on conventional petroleum-based binders.

Figure 4. Marshall Stability Test of Modified Bituminous Mix

Figure 4 illustrates the Marshall Stability test performed on the modified bituminous specimens. Cylindrical specimens prepared using different percentages of plastic and crumb rubber are subjected to compressive loading until failure. The maximum load sustained before failure is recorded as the Marshall Stability value, while the corresponding deformation is measured as the flow value. The modified specimens exhibited considerably higher stability than conventional bitumen, indicating improved load-bearing capacity and enhanced resistance to permanent deformation. The increased stability is attributed to the improved flexibility and cohesive characteristics of the modified binder, which provides stronger bonding between aggregates. The laboratory results confirm that plastic/rubber modified bitumen possesses superior structural strength and can effectively withstand heavy traffic loads, making it highly suitable for flexible pavement construction.

Figure 5. Construction of Plastic/Rubber Modified Road

Figure 5 shows the construction stage of the plastic/rubber modified road. The prepared modified hot mix is transported to the site, laid using an asphalt paver, and compacted with heavy rollers to achieve the required density and smooth surface finish. Proper compaction enhances aggregate interlocking and minimizes air voids, resulting in improved pavement strength and durability. The modified binder exhibits excellent workability during paving while providing higher resistance to rutting, moisture penetration, and thermal deformation. The construction process demonstrates that plastic/rubber modified mixtures can be handled using conventional road construction equipment without requiring significant changes in construction practice. The resulting pavement possesses enhanced structural performance and longer service life while simultaneously promoting environmentally sustainable road construction through waste recycling.

VII. CONCLUSION

The present study successfully investigated the Design of Bitumen Modified with Plastic/Rubber Road by utilizing waste plastic and crumb rubber as sustainable modifiers for conventional bitumen. The modified bituminous mixtures were prepared using controlled laboratory procedures and evaluated through standard engineering tests including the penetration test, softening point test, ductility test, viscosity test, specific gravity test, and Marshall Stability test. The experimental investigation demonstrated that the incorporation of plastic and rubber waste significantly improves the engineering properties of bitumen while simultaneously addressing the environmental challenges associated with non-biodegradable waste disposal. The modified binder exhibited improved adhesion, elasticity, and thermal stability, making it suitable for flexible pavement construction under varying traffic and climatic conditions.

The laboratory results indicated that the Marshall Stability of the modified bituminous mix increased considerably compared with conventional bitumen, demonstrating enhanced load-bearing capacity and improved resistance to permanent deformation. The modified pavement also showed higher resistance to rutting, fatigue cracking, moisture damage, and temperature-induced distress. The increase in softening point and reduction in penetration value confirmed improved high-temperature performance, while the optimized bitumen content maintained satisfactory flexibility and workability during pavement construction. These improvements contribute to longer pavement service life, reduced maintenance requirements, and better riding quality for highway users.

The study further confirmed that the use of waste plastic and crumb rubber provides significant environmental and economic benefits. Recycling these waste materials reduces landfill accumulation, minimizes environmental pollution, lowers the consumption of virgin bitumen, and decreases overall road construction costs. The use of recycled polymers also supports sustainable infrastructure development by promoting circular economy principles and efficient utilization of waste resources. The modified pavement can be constructed using conventional road construction equipment without requiring major changes in construction techniques, making its practical implementation both feasible and cost-effective.

Overall, the proposed methodology demonstrates that plastic/rubber modified bitumen is a reliable, durable, and environmentally friendly alternative to conventional paving materials. The combination of improved mechanical performance, enhanced durability, lower maintenance costs, and sustainable waste management makes this technology highly suitable for modern highway construction. Future research may focus on evaluating the long-term field performance of modified pavements under different climatic conditions, incorporating nanomaterials, warm mix asphalt technology, fiber reinforcement, Artificial Intelligence-based mix optimization, and smart pavement monitoring systems to further improve pavement quality, sustainability, and service life.

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