International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 04 | Apr 2024 www.irjet.net p-ISSN: 2395-0072

Improving The Strength of Highway Pavement By Using The Electronic Waste

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Abstract - *The presence of toxic plastic in Municipal Solid Waste (MSW) is a growing concern, as it accounts for nearly 5% of such waste. The non-biodegradable nature of plastic poses significant environmental pollution and hygiene problems, leading to the need for proper disposal management. However, recent experimentation conducted at various institutes has shown that waste plastic can be effectively utilized in road construction through asphalting. This approach is based on economic considerations, as bitumen is commonly used as a binder in road making processes. By modifying bitumen with plastic waste, a mix can be created that serves as a top layer of flexible pavement with superior binding properties, stability, density and resistance to water. In this project, we tested the use of waste plastic mixed with bitumen at varying percentages - 0%, 3%, 5%, 8%, and 10%. Our results showed that the addition of plastic led to decreases in penetration and ductility values while increasing softening point, flash point, and fire point values. Overall, utilizing waste plastic in road construction offers an innovative solution to address both environmental concerns and economic considerations associated with proper waste management practices.*

Key Words: Bitumen, highway Pavement, Plastic waste, Strength, Ductility, Road construction.

1.BACKGROUND INFORMATION ON HIGHWAY PAVEMENT CONSTRUCTION

Highway pavement construction encompasses a meticulous process that begins with thorough site preparation, involving clearing, grading, and preparing the subgrade to meet required specifications. The subsequent installation of the base course, comprising compacted layers of aggregates, establishes a stable foundation for the pavement. Depending on the type of pavement—flexible or rigid—either hot mix asphalt or concrete is meticulously placed and compacted to form the surface. Compaction, a critical step, eliminates air voids and ensures the desired density, while curing promotes proper hydration of concrete or adhesion of asphalt. Throughout construction, quality control measures, including tests for density, thickness, and material properties, are rigorously implemented to uphold standards. Beyond construction, ongoing maintenance is paramount, involving activities like crack sealing and resurfacing to prolong pavement life. Environmental considerations, such as sustainability and drainage design, are integral, underscoring the need for eco-friendly practices and proper water management.

Highways are intricate webs of asphalt and concrete that crisscross landscapes, bridging cities, towns, and rural areas. These ribbons of roadway serve as lifelines for economies, enabling the seamless flow of goods, services, and people. They are the arteries of commerce, facilitating the movement of freight from manufacturing centers to markets and connecting consumers with the products they need. Highways are also the conduits of connection, providing commuters with the means to traverse vast distances efficiently, whether for work or leisure. From the bustling urban freeways that pulse with activity to the tranquil rural routes that wind through picturesque countryside, highways are not merely conduits for transportation but also pathways for exploration and discovery. They embody the spirit of progress, evolving alongside technological innovations to meet the ever-changing needs of society. Yet, amidst their undeniable utility and significance, highways also present challenges, from traffic congestion and environmental impact to safety concerns. As we navigate the road ahead, it is imperative to strike a balance between efficiency, sustainability, and safety to ensure that highways continue to serve as vital lifelines for generations to come.

Figure-1: Highway Pavement

2.IMPORTANCE OF PAVEMENT STRENGTH FOR DURABILITY AND SAFETY

The importance of pavement strength for durability and safety cannot be overstated, especially when considering transportation infrastructure. Here are several key reasons why pavement strength is crucial for both durability and safety:

Load-Bearing Capacity: Pavement strength determines the ability of the surface to withstand various loads imposed by vehicles, including cars, trucks, and buses. A pavement with inadequate strength may develop cracks, rutting, or even structural failure under heavy loads, leading to safety hazards and reduced service life.

Resistance to Distress: Strong pavement resists distress mechanisms such as fatigue cracking, rutting, and pothole formation. These distresses can compromise the integrity of the pavement, leading to unsafe driving conditions and costly repairs or rehabilitation.

Traffic Safety: Pavement strength contributes to the overall safety of road users by providing a stable and smooth driving surface. Weak pavements can lead to uneven surfaces, which may cause loss of vehicle control, skidding, or accidents, particularly during adverse weather conditions.

Durability: Pavement strength directly influences the longevity and durability of the road infrastructure. A strong pavement can withstand repeated traffic loads and environmental factors such as temperature variations, moisture, and chemical exposure, thus extending its service life and reducing maintenance costs.

Economic Impact: Pavement strength plays a significant role in minimizing lifecycle costs associated with road maintenance and rehabilitation. Investing in high-strength pavements upfront can result in long-term cost savings by reducing the frequency and extent of repairs and replacements.

User Comfort: A pavement with adequate strength provides a smoother ride quality, enhancing user comfort and reducing driver fatigue. This is particularly important for long-distance travel and for vulnerable road users such as cyclists and pedestrians.

3.ELECTRONIC WASTE (E-WASTE) AND ITS ENVIRONMENTAL IMPACT

Electronic waste (e-waste) presents significant environmental challenges due to the presence of hazardous materials like lead, mercury, and brominated flame retardants in electronic devices. Improper disposal methods, such as landfilling and incineration, release toxic substances into the soil, water, and air, leading to contamination and air pollution. Additionally, e-waste contributes to resource depletion, energy consumption, and climate change, while informal recycling practices further exacerbate ecosystem damage and biodiversity loss. Addressing these challenges requires effective e-waste management systems, sustainable product design, consumer education, and regulatory enforcement to promote responsible disposal and recycling practices globally.

4.FACTORS AFFECTING PAVEMENT DURABILITY AND LIFESPAN

Several factors significantly impact pavement durability and lifespan. These include:

Traffic Load and Volume: The magnitude and frequency of traffic loads, including the types of vehicles and their weights, directly influence pavement durability. High volumes of heavy traffic accelerate pavement deterioration, leading to premature wear and reduced lifespan.

Climate and Weather Conditions: Environmental factors such as temperature fluctuations, freeze-thaw cycles, rainfall, and UV radiation can degrade pavement materials over time. Regions experiencing extreme weather conditions may require pavements designed to withstand temperature variations and moisture ingress to ensure long-term durability.

Subgrade Soil Characteristics: The properties of the subgrade soil beneath the pavement, such as strength, stiffness, and drainage capacity, significantly affect pavement performance. Poor soil conditions can lead to inadequate support, settlement, and pavement distress, compromising durability and lifespan.

Material Selection and Quality: The selection of appropriate pavement materials, including aggregates, asphalt binders, and additives, is crucial for achieving desired performance and durability. High-quality materials with proper gradation, durability, and compatibility enhance pavement resistance to distress mechanisms and extend its service life.

Design and Construction Practices: Proper pavement design and construction techniques, including adequate thickness, compaction, and joint construction, are essential for ensuring structural integrity and longevity. Poor design or construction practices can result in inadequate load-bearing capacity, surface distress, and premature deterioration.

Maintenance and Rehabilitation: Regular maintenance activities such as crack sealing, pothole patching, and pavement overlays can extend the lifespan of existing pavements by addressing minor defects and preventing further deterioration. Timely rehabilitation measures, such as resurfacing or reconstruction, are necessary to restore structural integrity and prolong pavement service life.

5.CURRENT LIMITATIONS OF TRADITIONAL PAVEMENT CONSTRUCTION MATERIALS

The current limitations of traditional pavement construction materials stem from their susceptibility to various forms of deterioration and their environmental impact. Conventional materials like hot mix asphalt (HMA) and Portland cement concrete (PCC) often exhibit reduced durability over time, manifesting in issues such as cracking, rutting, and spalling, which necessitate frequent maintenance interventions. Moreover, the extraction, production, and transportation of these materials entail significant resource consumption and carbon emissions, contributing to environmental degradation and climate change. Their limited flexibility, resilience, and recyclability further exacerbate these challenges, making them ill-suited for addressing the evolving needs of modern infrastructure systems. To overcome these limitations, there is a growing imperative to invest in sustainable alternatives that offer enhanced durability, reduced environmental impact, and improved lifecycle performance, thus ensuring the long-term resilience and sustainability of pavement infrastructure.

6.METHODOLOGY

Bituminous mix consists of a mixture of aggregates continuously graded from maximum size, typically less than 25 mm, through the fine filler that is smaller than 0.075mm. Sufficient bitumen is added to the mix so that the compacted mix is effectively impervious and will have acceptable dissipative and elastic properties.

6.1.MATERIAL USED

Highway pavement construction involves several materials, each serving specific functions to ensure durability, safety, and smoothness. Here are the primary materials used:

The basic materials used are as follows:

1. Aggregates
2. Fly Ash
3. Slag
4. Bituminous Binder
5. E Waste.

6.1.1.Aggregates

Aggregates are the fundamental building blocks of highway pavement, playing a crucial role in its strength and durability. These materials, typically sourced from natural rock deposits or recycled materials like concrete or asphalt, are selected based on their physical properties like particle size, shape, and strength. They provide stability, support, and resistance to wear and tear under heavy traffic loads. Properly graded aggregates create a dense matrix, enhancing the pavement's load-bearing capacity and preventing cracking and rutting. Their composition directly influences pavement performance, making the selection process vital for ensuring the longevity and safety of road infrastructure.

Figure-2: Coarse Aggregate

6.1.2.Fly Ash

Fly ash, a byproduct of coal combustion in power plants, finds valuable application in highway pavement construction. Its inclusion in concrete mixtures enhances workability, reduces permeability, and improves long-term strength. As a supplementary cementitious material, fly ash mitigates environmental impact by reducing the need for Portland cement, thus cutting down on carbon emissions. Its pozzolanic properties react with calcium hydroxide to form additional cementitious compounds, enhancing durability and reducing the risk of alkali-silica reaction. Utilizing fly ash in highway pavement not only strengthens infrastructure but also promotes sustainable practices by repurposing industrial waste into a valuable construction resource.

Figure-3: Fly Ash

6.1.3.Slag

Slag, a byproduct of steel manufacturing, serves as a beneficial component in highway pavement construction. Its incorporation as a supplementary cementitious material enhances the performance and durability of concrete mixtures. With its hydraulic properties, slag contributes to increased strength, reduced permeability, and improved resistance to chemical attacks and abrasion. By replacing a portion of Portland cement, slag helps to reduce greenhouse gas emissions associated with cement production. Additionally, its use in pavement construction provides a sustainable solution for managing industrial waste. Overall, slag plays a vital role in enhancing the strength, longevity, and environmental sustainability of highway pavements.

Figure-4: Slag

6.1.4.Bituminous Binder

Bituminous binder, a crucial component in highway pavement, is derived from petroleum refining. This viscous black substance, commonly known as asphalt, acts as the adhesive that binds aggregate particles together in asphalt concrete. Its flexibility enables the pavement to withstand varying temperatures and traffic loads without cracking. Bituminous binders come in various types and grades tailored to specific climate and traffic conditions. They provide waterproofing properties, protecting the underlying layers from moisture damage. With regular maintenance, bituminous binder prolongs pavement life, ensuring smooth and safe travel for road users. Its versatility and durability make it an indispensable element in highway infrastructure worldwide.

Figure-5:Bitumen Binder

6.1.5.E Waste

Utilizing e-waste in highway pavement presents an innovative solution to address both environmental and infrastructure challenges. Electronic waste, comprising discarded electronic devices, is recycled and processed into sustainable construction materials. Incorporating e-waste aggregates in pavement not only reduces the burden on landfills but also enhances pavement performance. These materials offer advantages such as improved strength, reduced material costs, and enhanced durability. Furthermore, by diverting e-waste from disposal sites, this approach contributes to environmental conservation and promotes circular economy principles. Implementing e-waste in highway pavement demonstrates a progressive approach towards sustainable infrastructure development, balancing resource efficiency with environmental stewardship.

Figure-6: Electronic Waste

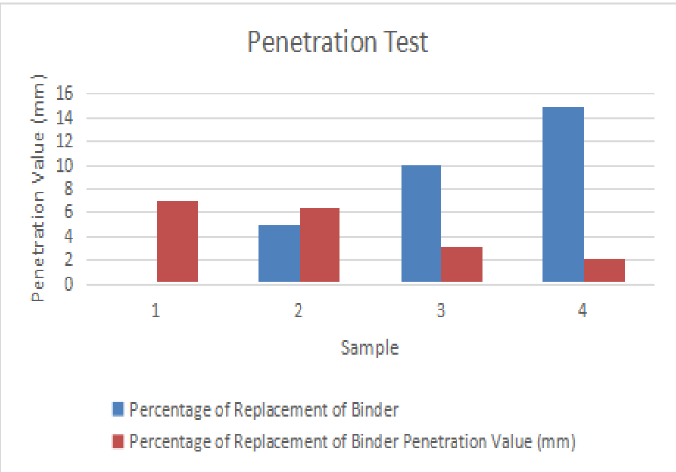
7.RESULT AND ANALYSIS

In this section, we will know the experimental study of replacement of the bitumen binder at different percentage, the details of the test is given below:

1. Penetration Test
2. Softening Point Test
3. Fire Point Test

7.1.Penetration Test of Bitumen

Penetration testing for bitumen involves evaluating the consistency and softness of bitumen, crucial for assessing its suitability for various applications in construction and road paving. This test measures the depth in tenths of a millimeter that a standard needle penetrates vertically into a sample of bitumen under specific conditions of time, temperature, and loading. Typically conducted at 25°C or 77°F, the penetration depth provides insights into bitumen's viscosity and grade, helping determine its performance characteristics like adhesion, cohesion, and durability. Standardized procedures ensure consistency and reliability in results, aiding engineers and manufacturers in selecting the appropriate grade of bitumen for different climate conditions and traffic loads. Penetration tests not only assure quality control but also contribute to enhancing the longevity and resilience of asphalt pavements, crucial for sustainable infrastructure development.



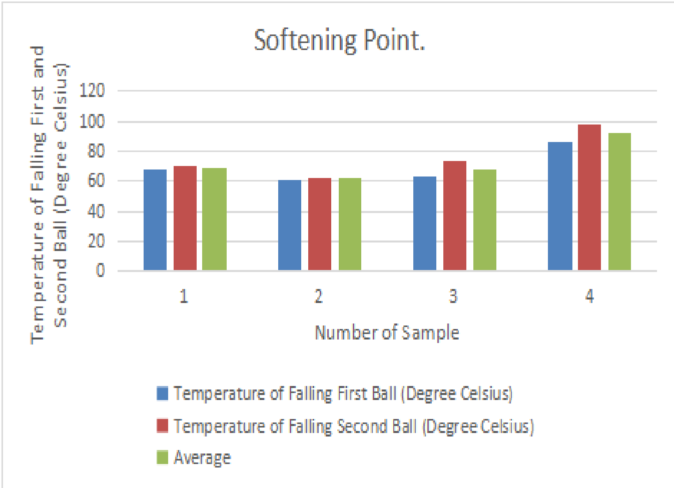
Graph-1: Penetration Test of Bitumen.

7.2.Softening Point Test of Bitumen

The Softening Point Test is a crucial assessment in determining the thermal susceptibility of bitumen, a vital component in road construction. Conducted according to standardized methods like ASTM D36 or ISO 4625, the test measures the temperature at which a bitumen sample softens under specific conditions.

In the procedure, a bitumen specimen is subjected to increasing temperature at a controlled rate, often using a ring-and-ball apparatus. As the temperature rises, the bitumen softens and allows the steel ball to descend. The softening point is recorded as the temperature at which the bitumen sample deforms to a specific distance, typically 25 millimeters.

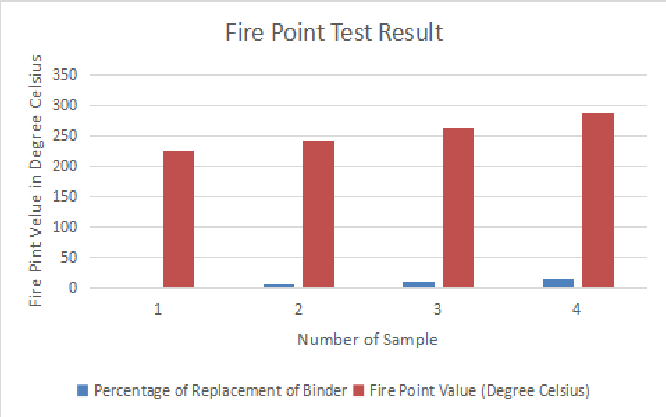
This test is essential for ensuring the suitability of bitumen for various climates and traffic conditions. Bitumen with higher softening points tends to withstand elevated temperatures better, offering superior resistance to deformation and rutting on roads. Understanding a bitumen's softening point aids in selecting appropriate grades for construction projects, optimizing road performance, and ensuring durability of road surfaces.



Graph-2: Softening Point Test for Bitumen.

7.3.Fire Point Test for Bitumen

The Fire Point Test for bitumen determines the temperature at which bitumen emits enough vapor to ignite momentarily when exposed to a flame under specific conditions. The test involves heating a sample of bitumen in a closed cup apparatus at a controlled rate. A small flame is passed over the surface of the bitumen at regular intervals. The temperature at which the bitumen momentarily catches fire and sustains combustion for at least five seconds is recorded as the fire point. This parameter is crucial in assessing the suitability of bitumen for various applications, especially in environments where high temperatures are encountered, such as in hot climates or near sources of heat. A higher fire point indicates better resistance to ignition and can be indicative of the bitumen's performance in safety-critical scenarios.



Graph-3: Fire Point Test of the Bitumen.

8.CONCLUSION

In this study, we examined the replacement of bitumen binder in highway pavement with electronic waste at varying percentages: zero, five, ten and fifteen percent. The tests conducted to assess the behavior of bitumen binder mixed with electronic waste included penetration test, softening point test, flash and fire point test, and ductility test. Our findings indicate that replacing five percent of the bitumen binder with electronic waste resulted in an 8.45% decrease in penetration value while a 54.93% decrease was observed when ten percent of the binder was replaced by electronic waste. As illustrated in chapter four's softening point graph, there is an increase in softening point as more electronic waste is added to the mixture until a certain threshold after which further additions lead to decreased softening points for bitumen binders mixed with high levels of electronic waste.

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