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Review of Dense Grade Bituminous Mixes with Natural Fiber Modified Coal Ash Incorporation

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Abstract- Coal-fired thermal power plants in India generate significant fly ash and bottom ash, posing environmental hazards. This review explores repurposing these byproducts in bituminous paving materials, with bottom ash as fine aggregate, fly ash as mineral filler, and sisal fibers to enhance engineering properties. The methodologies adhere to Ministry of Road Transport and Highways (MORTH, 2013) specifications, focusing on dense graded bituminous macadam (DBM) with a nominal maximum aggregate size of 26.5 mm. Sisal fibers coated with slow-setting emulsion (SS1) improve the mix, showing optimal performance with VG30 bitumen. Key findings include a Marshall stability of 15 kN, optimal bitumen content of 5.57%, and optimal fiber content and length of 0.5% and 10 mm, respectively. Performance tests reveal enhanced moisture susceptibility, indirect tensile strength, and creep behavior. This sustainable approach offers a viable alternative to traditional materials, promoting resource-efficient and resilient infrastructure development.

Keywords- Bottom ash, Fly ash, Sisal fiber, Emulsion, Indirect tensile strength, Static creep test, Tensile strength ratio.

I. INTRODUCTION

Roads, highways, and pavements stand as the backbone of a country, serving as the critical infrastructure upon which progress and development hinge. Most nations actively pursue programs aimed at either constructing new road networks or enhancing existing ones. The construction of both flexible and rigid pavements involves substantial investments to ensure optimal performance and the creation of durable, smooth surfaces that withstand the test of time.

1. Background of Study

In the context of India, where highways play a pivotal role in the transportation network, the Government has consistently allocated significant financial resources for the development and maintenance of pavement infrastructure. Undertaking a meticulous engineering study becomes paramount in optimizing investments and ensuring the longevity and reliable performance of the highways in service.

In the realm of flexible pavements, the focus shifts to two crucial aspects: pavement design and mix design. Pavement design involves the strategic planning and layout of the road surface to accommodate the expected traffic loads and environmental conditions. Mix design, on the other hand, pertains to the composition of materials, particularly bituminous mixes, to achieve the desired engineering properties and performance characteristics.

The current research study is specifically oriented towards exploring the engineering properties of bituminous mixes that are crafted from alternative or nonconventional materials. By delving into the use of such materials, the research aims to assess their viability and effectiveness in pavement construction. This approach aligns with the broader goal of sustainable and cost-effective infrastructure development, promoting innovation and resource efficiency in the construction and maintenance of vital transportation networks.

As nations strive for efficient and resilient highway systems, the incorporation of alternate materials in bituminous mixes emerges as a promising avenue. This research not only contributes to the scientific understanding of these unconventional materials but also holds the potential to revolutionize the way pavements are designed and constructed. Ultimately, the pursuit of innovative engineering solutions is key to ensuring the robustness and longevity of the highways that form the lifelines of a nation's connectivity and economic prosperity.

2. Bituminous Mix Design

Bituminous pavement is a composite material consisting of a blend of stone chips, carefully graded according to the nominal maximum aggregate size (NMAS). This graded mixture includes the fine fraction, particles smaller than 0.075 mm, which is combined with a suitable amount of bitumen. The objective is to create a mix that can be compacted effectively, resulting in smaller air voids within the pavement. The desired outcome is a mixture with optimal dissipative and elastic properties.

3. Types of Bituminous Mixes

Bituminous mixes are combinations of mineral aggregates and binders used in road construction. These mixes are designed to create a durable and stable road surface. Here are various types of bituminous mixes:

Hot Mix Asphalt

Hot Mix Asphalt (HMA) is a widely used bituminous mix in road construction. It is prepared by heating bitumen binder and dry aggregates to high temperatures, typically between 150°C to 160°C (300°F to 330°F). This process results in a consistent mixture that is easy to work with and allows for optimum air content compaction, providing better stability. HMA is commonly employed on highly trafficked roadways such as highways, airfields, and racetracks due to its durability and ability to withstand heavy traffic loads. Types of HMA are,

- Dense Graded Bituminous Macadam (DBM)
- Stone Matrix Asphalt (SMA)
- Open-Graded Mixes

Cold Mix Asphalt

Cold Mix Asphalt represents an innovative solution in bituminous mixes tailored for specific scenarios where high mixing temperatures are impractical. Unlike traditional hot mix asphalt (HMA), cold mix asphalt is produced at ambient temperatures, eliminating the need for extensive heating during the mixing process. The distinctive feature of cold mix asphalt is its utilization of an emulsified bitumen—a combination of water and bitumen in proper proportions—blended with aggregates.

The production of cold mix asphalt involves the creation of a mixture that is easy to work with and compact. As the water in the emulsion evaporates, it leaves behind the bitumen, imparting cold mix asphalt with properties akin to cold HMAC (Hot Mix Asphalt Concrete). This unique process makes cold mix asphalt an ideal choice for patching and repairs on roads with lower traffic volumes.

Cut-back Asphalt

Cut-back asphalt represents a specific type of bituminous mix created through the dissolution of a lighter fraction of petroleum with bitumen binder. This process results in the production of a less viscous liquid that can effectively dissolve with aggregates. Cut-back asphalt is characterized by its lower viscosity, making it more manageable during the mixing and compaction phases of road construction.

Historically, cut-back asphalt has been widely used, offering practical advantages in terms of ease of application and workability. However, its popularity has waned in recent times due to environmental concerns associated with the volatile solvents used in the cut-back process.

Mastic Asphalt or Sheet Asphalt

Mastic Asphalt, also known as Sheet Asphalt, stands as a distinctive and durable type of bituminous mix utilized in various construction applications, from roadways to footpaths and flooring. The production of mastic asphalt involves a meticulous process wherein hard-grade blown bitumen undergoes heating in a green cooker or mixer. This heating transforms the bitumen into a highly viscous liquid before it is added to aggregates.

A distinguishing feature of mastic asphalt is the prolonged cooking or maturing process, lasting typically between 6 to 8 hours. This extended duration allows the mixture to achieve the desired characteristics before transportation to the construction site. Once at the site, mastic asphalt is laid in different thicknesses based on the intended application, whether for footpaths, roads, or flooring and roof installations.

The benefits of mastic asphalt include its robustness and resistance to wear and tear. It forms a durable surface that can withstand the stresses of heavy traffic and environmental conditions. Due to its impermeable nature, mastic asphalt serves well in various weather conditions, offering a reliable and long-lasting solution in construction projects.

3. Problem Statement

The challenge of procuring aggregates for bituminous mixes, specifically coarse, fine, and filler fractions, can lead to increased costs and environmental concerns due to long-distance transportation. However, an alternative lies in the vast quantities of coal ash generated by thermal power plants in India, which currently face disposal challenges. Approximately 120 million tons of ashes are produced annually by forty major thermal power plants. The conventional disposal methods involve either dry or wet disposal in open areas, artificial lagoons, or dumping yards near the plants. This raises significant issues related to land usage, potential health hazards, and environmental threats. To address these challenges, there is a critical need for a comprehensive study to explore the productive utilization of coal ash, mitigating its negative impact on the environment and society. The enormous volume of this waste material presents an opportunity for beneficial reuse that aligns with sustainable practices. Proper management and utilization of coal ash can potentially address the scarcity of aggregates for bituminous mixes while simultaneously minimizing the environmental footprint associated with conventional disposal methods.

In devising strategies for the utilization of coal ash in bituminous mixes, careful consideration must be given to the safety and well-being of human life, wildlife, and the environment. Approaches should focus on developing innovative technologies and engineering solutions to incorporate coal ash effectively into bituminous mixes, ensuring that the resulting materials meet industry standards for road construction while adhering to environmental and safety regulations. This type of research and development effort is essential to transform what was once considered waste into a valuable resource, contributing to sustainable infrastructure development and environmental conservation.

Objectives of Research

- Determine optimal use of coal ash as nonconventional aggregate in bituminous mixes.
- Investigate the impact of adding Sisal fiber to enhance bituminous mix performance.
- Assess fatigue resistance, moisture susceptibility, and creep value of the modified mixes in field conditions.
- Analyze the influence of Sisal fiber on stability, flexibility, and deformation resistance of bituminous mixes.
- Determine the best Sisal fiber content and length for improved engineering properties.
- Quantify improvements in fatigue, moisture resistance, and creep behavior.
- Assess sustainability and environmental implications of modified bituminous mixes.
- Provide practical recommendations for applying coal ash and Sisal fiber in road construction, considering cost-effectiveness and durability.

II. LITERATURE REVIEW

Dense Grade Bituminous Mixes (DG-BMs) form a critical component in modern road construction, offering a durable and cost-effective solution for transportation infrastructure. Over the years, researchers and engineers have explored innovative approaches to enhance the engineering properties of these bituminous mixes, addressing challenges related to stability, durability, and sustainability. The literature reveals several key themes and trends in the development of DG-BMs. Researchers have investigated the individual effects of coal ash and natural fibers on engineering properties, exploring their compatibility and potential synergy when combined. Understanding the historical evolution and current trends in this field is crucial for advancing sustainable and high-performance road construction practices. This literature review aims to provide a comprehensive synthesis of existing research on the development in engineering properties of DG-BMs with a specific focus on the utilization of coal ash and natural fibers. By examining historical perspectives, individual contributions, and potential synergies, this review aims to contribute to a deeper understanding of sustainable approaches in bituminous mix design.

Chandran Sreejith et al. (2023) made stride towards sustainable road construction practices by entirely substituting the conventional filler, such as quarry dust, with copper slag—a by-product sourced from the copper industry—in asphalt mixes. A parallel investigation within the study focused on the incorporation of glass fibers, ranging from 0.1% to 0.4% by volume, to assess their potential as a reinforcement strategy. The experimental outcomes of this research have shed light on an optimal composition, featuring copper slag as the filler and 8 mm glass fibers at a volume of 0.2%, revealing superior mechanical properties without compromising vital volumetric characteristics. This insightful research not only contributes to the ongoing discourse surrounding sustainable road construction but also offers valuable insights into the potential of innovative materials and their synergies in achieving optimal performance. The study addresses the imperative challenge posed by the escalating demands for road network expansion, driven by rapid economic growth. Traditional road construction practices, relying on broken stones as primary aggregates, have been instrumental in the significant depletion of natural resources. This depletion, coupled with the environmental challenge associated with the proper disposal of industrial waste, particularly the conventional filler like quarry dust, underscores the pressing need for alternative and sustainable solutions in the field of road construction.

Hadiwardoyo, Sigit Pranowo (2013) focused on the failure of surface layers of roads due to temperature changes and traffic loads. This study experimented with short coconut fibers in bitumen mix, varying the percentage of coconut fibers from 0.5% to 1.50% with an increment of 0.25%. The fiber size was also varied, including 5mm, 7.5mm, 10mm, and 12.5 mm. The bitumen characteristics were tested with coconut fibers. Results from the Marshall properties test showed that Marshall stability increased by 10-15% with the addition of 0.75% fiber content and 5-mm fiber length by weight of the mixture. The study also observed that the addition of fiber changed the bitumen property with a lower penetration value. This research sheds light on the potential of coconut fibers to enhance the properties of bituminous mixes, emphasizing their impact on stability and texture.

Gunalaan Vasudevan et al. (2013) embarked on a comprehensive study focused on examining the performance characteristics of bottom ash within Hot Mix Asphalt (HMA). The central thrust of this research was to explore the potential use of bottom ash as aggregates in critical layers of road construction, namely sub-bases, bases, and pavement layers. This investigation was underpinned by a three-pronged objective. Firstly, the study sought to assess the stability of bitumen mixtures crafted with varying percentages of bottom ash, leveraging the well-established Marshall Method. Secondly, it aimed to discern the physical characteristics of bottom ash when amalgamated with bitumen. Finally, the research delved into evaluating the consequential enhancement of engineering properties in the Marshall cube, focusing particularly on texture and appearance. The experimental outcomes yielded promising insights, revealing that samples incorporating bottom ash exhibited superior performance compared to conventional samples in terms of stiffness, strength, and flow. This promising outcome suggests that pavements constructed with such mixtures could potentially demonstrate heightened strength and resilience to the stresses imposed by high traffic loads. However, the study also uncovered a notable drawback in the use of coal bottom ash as a mineral filler. This particular application resulted in an undesirable increase in air void content within the mixture, leading to a reduction in overall density. This finding underscores the need for a nuanced consideration of the trade-offs associated with incorporating bottom ash into HMA mixes, weighing the advantages in stiffness and strength against the potential drawbacks related to air void content and density reduction. Ultimately, Vasudevan's research contributes valuable insights to the ongoing discourse on sustainable and optimized materials for road construction, highlighting both the potential benefits and challenges associated with utilizing bottom ash in asphalt mixes.

Boyes, Anthony John. (2011) explored the possible effects of fly ash as a mineral filler in asphalt mixes to reinforce and reduce bituminous moisture-induced damage. The anti-stripping effect of two waste products, cement kiln dust (CKD), and fly ash, was investigated by comparing them with hydrated lime and an amine-based chemical additive. Observations revealed that Class C fly ash can be used as an anti-stripping additive in asphalt mix, albeit at a higher cost than amine chemicals or lime. Dynamic shear rheometer tests showed that fly ash additives stiffened the asphalt binder. Overall, specimens treated with 5% Class C fly ash and 1.5% hydrated lime demonstrated the greatest overall resistance to moisture damage. Combinations of 5% and 7% Class C fly ash and 1.5% and 2% lime were determined to have significantly higher conditioned compressive strengths than the control.

Sinha, A. K., et al. (2009) conducted tests on sub-soil for a proposed road construction of a 4 km stretch with pond ash running from Kalindi Colony to Kalindi Kunj in New Delhi, India. Field tests, such as Standard Penetration Test (SPT) and Cone Penetration Test (CPT), were conducted. Based on laboratory experiments and field results, the design of a pond ash embankment with and without a berm was done under two types of conditions: steady seepage and sudden drawdown with a seismic factor. The study observed that under the highest flood level with seismic effects, the fly ash embankment is exposed to both sudden drawdown and steady seepage conditions. This research provides valuable insights into the use of pond ash in embankment construction and its performance under different conditions, contributing to the knowledge base for sustainable road infrastructure.

Partl, Manfred, K. Sokolov, and H. Kim. (2008) conducted a laboratory study on a special type of carbon fiber grid placed at different depths in asphalt pavements. The study aimed to obtain design information about the position of the grid that would yield optimum results. Two different types of asphalt pavements were examined: asphalt concrete and mastic asphalt. The study revealed that the addition of a carbon grid increased stiffness, failure strain, stress, and resistance against low-temperature cracking. However, rutting tests with a Model Mobile Traffic Load Simulator (MMLS) found that the grid did not improve resistance against flow value in the mastic asphalt layer.

Kar, Debashish (2007) investigated the effect of indigenously available sisal fiber on SMA and bituminous concrete (BC) mixtures. Sisal fiber was considered both as an additive for BC mix and a stabilizing agent for SMA mix. The fiber content varied from 0% to 0.5% by weight of the total mix, while the binder content was varied from 4% to 7%. Fly ash was used as the mineral filler due to its satisfactory results in the initial stage of the experiment. The BC and SMA mixes underwent various tests, including Drain-down test, Static Creep test, and Static Indirect Tensile Strength Test. Results from Marshall properties tests showed that the addition of fiber improved Marshall Stability and indirect tensile strength while reducing Drain-down. The indirect tensile strength of the SMA mixture was observed to be better than that of the BC mixture. Optimum binder content for BC and SMA was found to be 5% and 5.2%, respectively, while the optimum fiber content was 0.3%. This study highlights the positive impact of fiber addition on the properties of both BC and SMA mixtures, providing valuable insights into their optimal composition.

III. CONCLUSION

This review underscores the promising potential of repurposing byproducts from coal-fired thermal power plants, particularly bottom ash and fly ash, in the construction of bituminous pavements. Utilizing these waste materials as fine aggregate and mineral filler, respectively, along with the inclusion of natural sisal fibers, addresses significant environmental challenges and offers an economically viable alternative to traditional construction materials.

The findings from various studies indicate that dense graded bituminous mixes prepared according to MORTH (2013) standards, and enhanced with VG30 bitumen, exhibit superior performance characteristics. Optimal mix parameters, such as a Marshall stability of 15 kN, bitumen content of 5.57%, and sisal fiber content and length of 0.5% and 10 mm, respectively, contribute to improved moisture resistance, indirect tensile strength, and creep behavior.

In conclusion, the integration of coal ash and natural fibers into bituminous paving materials not only mitigates the disposal issues associated with coal ash but also conserves natural resources, paving the way for sustainable and resilient infrastructure development. This approach presents a viable path forward for greener engineering practices, promoting environmental sustainability and resource efficiency in the construction industry.

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