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A STUDY ON DEVELOPMENT IN ENGINEERING PROPERTIES OF DENSE GRADE BITUMINOUS MIXES WITH COAL ASH BY USING NATURAL FIBER

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ABSTRACT

Flexible pavements under heavy traffic loading often experience permanent deformation, rutting, and fatigue cracking, demanding bituminous mixes with enhanced shear strength and structural stability. This laboratory study evaluates the volumetric and mechanical properties of Dense Bituminous Macadam (DBM) modified using naturally available Sisal fiber as a stabilizing additive and industrial coal ash (passing 75microns sieve) as a sustainable alternative mineral filler replacing conventional Ordinary Portland Cement (OPC). Aggregates conforming to MoRTH (5th Revision) gradation limits and 60/70 penetration grade bitumen were utilized. Marshall test specimens were prepared with 75 compaction blows on each face across varying binder contents (5.0% to 6.0%) and fiber concentrations (0% to 0.5% by total mix weight, cut to 15 to 20mm lengths). Comparative filler analysis demonstrated that coal ash delivers comparable structural performance to OPC, achieving a peak unmodified stability of 14.38 kN at 5.5% bitumen content. Experimental results established the Optimum Binder Content (OBC) as 5.5% and the Optimum Fiber Content (OFC) as 0.3%. At the optimum mix design (5.5% OBC with 0.3% OFC), the modified DBM mix exhibited a maximum Marshall Stability of 14.55 kN and a reduced flow value of 3.1 mm. Volumetric analysis confirmed full compliance with MoRTH specifications. The insertion of Sisal fiber forms a reinforced three-dimensional matrix within the bituminous mastic, mitigating binder drain-down and increasing shear resistance under dynamic loads. The study demonstrates that combining natural Sisal fiber with byproduct coal ash yields an economically viable, eco-friendly, and high-performance flexible pavement material.

Keywords: Dense Bituminous Macadam (DBM), Sisal Fiber, Coal Ash Filler, Marshall Mix Design, Optimum Binder Content (OBC), Optimum fiber content (OFC), Volumetric Parameters, MoRTH Specifications.

I. INTRODUCTION

Construction of highway involves huge outlay of investment. A precise engineering design may save considerable investment as well a reliable performance of the in-service highway can be achieved. Two things are of major considerations in flexible pavement engineering–pavement design and the mix design. The present study is related to the mix design considerations.

A good design of bituminous mix is expected to result in a mix which is adequately (i) strong, (ii) durable, (iii) resistive to fatigue and permanent deformation, (iv) environment friendly, (v) economical and so on. A mix designer tries to achieve these requirements through a number of tests on the mix with varied proportions and finalizes with the best one. The present research work tries to identify some of the issues involved in this art of bituminous mix design and the direction of current research.

II. LITERATURE SURVEY

Bradely et al. (2004) studied Utilization of waste fibers in stone matrix asphalt mixtures. They used carpet fiber and polyester fibers and waste tires to improve the strength and stability of mixture compared to cellulose fiber. They found waste tire and carpet fiber are effective in preventing excessive drain down of SMA mixture also found that tensile strength ratio of mixes more than 100% , it means fiber don't weaken the mixture when expose to moisture. Addition of tire and carpet fiber increases toughness of SMA. They found no difference in permanent deformation in SMA mix containing waste fibers as compared to SMA mix containing cellulose or mineral fiber.

Kamaraj et al. (2004) carried laboratory study using natural rubber powder with 80/100 bitumen in SMA by wet process as well as dense graded bituminous mix with cellulose fiber and stone dust and lime stone as filler and found its suitability as SMA mix through various tests.

Muniandy and Huat (2006) used Cellulose oil palm fiber (COPF) and found fiber-modified binder showed improved rheological properties when cellulose fibers were pre blended in PG64-22 binder with fiber proportions of 0.2%,0.4%,0.6%,0.8 %and 1.0% by weight of aggregates. It showed that the PG64-22 binder can be modified and raised to PG70-22 grade. The Cellulose oil palm fiber (COPF) was found to improve the fatigue performance of SMA deign mix. The fatigue life increased to a maximum at a fiber content of about 0.6%, while the tensile stress and stiffness also showed a similar trend in performance. The initial strains of the mix were lowest at a fiber content of 0.6%.

Kumar et al.(2007) studied on 2 types of fiber. Tried to use a fiber in SMA by taking jute fiber which is coated with low viscosity binder and compare the result with an imported cellulose fiber (a cellulose fiber imported from Germany) using 60/70 grade bitumen. and found optimum fiber percentage as 0.3% of the mixture. Jute fiber showed equivalent results to imported patented fibers as indicated by Marshall Stability Test, permanent deformation test and fatigue life test. Aging index of the mix prepared with jute fiber showed better result than patented fiber.

Thulasirajan and Narasimha (2011) carried out laboratory studies on coir Fiber reinforced bituminous concrete. Marshall stability, flow and volumetric properties of bituminous concrete with coir Fibers of different lengths 10 mm, 15 mm and 20 mm with different dosages 0.3% 0.5% and 0.7% were investigated. It was concluded that bituminous concrete added with 15 mm Fiber length at a dosage of 0.52 % provided better stability and volumetric properties. The addition of Fibers increased the air voids by 79% and VMA by 16%. The unit weight decreased by 1% and voids filled with bitumen decreased by 14%. The addition of coir Fibers enhanced the properties of bituminous mixes by increasing their stability, air voids and decreasing the flow.

Abiola et al. (2014) reviewed the utilisation of natural Fibers as modifiers in bitumen mixes. Utilisation of jute Fiber, coconut coir, sisal fiber and hemp Fiber was discussed. Fibers were added to improve the tensile strength and flexibility of their bitumen mixes. The authors concluded that reinforcement with natural Fibers provided an improvement in fatigue life and increased stability. They recommended further studies on the application of natural Fibers in modifying dense graded bituminous mixes.

Narayan (2010) carried out laboratory investigations on the usage of sisal Fiber in stone matrix asphalt for Indian roads. In this study samples were prepared with and without Fibers to compare their properties. Samples were prepared with a bitumen content of 4%, 5%, 5.5%, 6%, 6.5% and 7% and optimum bitumen content arrived by Marshall method was 5.3%. With the addition of Fibers, the stability increased by 9% and the flow value increased by 1%. It was concluded that additional performance tests such as indirect tensile test, fatigue test and wheel rutting test had to be carried out for arriving at final conclusions.

Kumar et al. (2004) carried out a study on the use of jute Fibers in SMA. Laboratory investigations were conducted to assess the feasibility of jute Fibers against synthetic Fibers in gap graded mix. Synthetic Fibers of 6mm length with 0.045mm thick and jute Fibers of 6 mm length with 0.090 mm thickness were used for the study. The bitumen content of bituminous mix with synthetic Fiber and natural Fiber was 6.2% and 6.1%, respectively, with 0.3% Fiber content by weight of the mix. The Marshall stability value of bituminous mix with synthetic Fiber and natural Fiber was 7.1 kN and 7.4 kN against the requirement of 6.2 kN. The tensile strength ratio and creep potential of the bituminous mix with natural Fiber and synthetic Fiber were comparable. The stiffness modulus of the bituminous mix with synthetic Fiber and natural Fiber was 645 MPa and 508 MPa at 350C. The stiffness modulus of mix added with synthetic Fiber was 1.27 times and 1.25 times higher than the stiffness modulus of mix added with natural Fiber at 350C and 250Crespectively.

Muniandy and Huat (2006) carried out laboratory tests on diametrical fatigue performance of stone matrix asphalt added with cellulose palm oil Fiber. The cellulose palm oil Fiber was added with 80-100 penetration bitumen in a wet process and the proportions of Fiber were from 0.2% to 1.0%, with an increment of 0.2% by weight of aggregate. The optimum bitumen content of bituminous mix without Fiber was in the range of 6.39-6.69%, whereas optimum bitumen content of bituminous mix with Fiber was in the range of 6.30-6.84%. For mix without Fiber the stability was in the range of 5-6.8 kN and resilient modulus was in the range of 2175 to 3060 MPa. For mix with cellulose Fiber the stability was in the range of 6.7-11.6 kN and resilient modulus was in the range of 3250 - 4350 MPa.

III. EXISTING SYSTEM

The conventional Dense Bituminous Macadam (DBM) mix primarily uses Ordinary Portland Cement (OPC) or stone dust as the mineral filler and 60/70 penetration grade bitumen as the binder. To improve pavement performance, previous studies have incorporated synthetic stabilizing additives such as cellulose fibers, mineral fibers, polyester fibers, polypropylene fibers, polymers, and rubber-modified binders. These materials are mainly intended to enhance Marshall stability, reduce drain-down, and improve resistance to rutting and fatigue.

Several researchers have also investigated the use of natural fibers such as jute, coir, and sisal in bituminous mixtures. Most of these studies focused on Stone Matrix Asphalt (SMA) or conventional bituminous concrete mixes using standard fillers, while only limited work has explored the combined use of natural fibers and industrial waste materials. Existing mix designs generally follow the Marshall method to determine the optimum binder content and evaluate properties such as stability, flow, air voids, and durability.

IV. PROPOSED SYSTEM

The proposed system develops an enhanced Dense Bituminous Macadam (DBM) mix by combining natural sisal fiber as a stabilizing additive with coal ash as an alternative mineral filler in place of Ordinary Portland Cement (OPC). The mix is designed using the Marshall Mix Design method by varying the bitumen content from 5.0% to 6.0% and the sisal fiber content from 0% to 0.5% to determine the Optimum Binder Content (OBC) and Optimum Fiber Content (OFC). This approach aims to improve the mechanical and volumetric properties of the pavement while promoting the use of renewable and industrial waste materials.

In the proposed methodology, aggregates conforming to MoRTH specifications, 60/70 penetration grade bitumen, coal ash passing through the 75-micron sieve, and chopped sisal fibers of 15–20 mm length are used to prepare the DBM specimens. Marshall Stability, Flow Value, Bulk Density, Air Voids, Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB) are evaluated to assess the performance of the modified mix. The addition of sisal fiber forms a reinforcing network within the bituminous matrix, while coal ash acts as an effective filler that enhances bonding, improves load-carrying capacity, reduces binder drain-down, and provides a sustainable alternative to conventional fillers.

V. SYSTEM ARCHITECTURE

The proposed system architecture illustrates the complete workflow for developing a Dense Bituminous Macadam (DBM) mix using coal ash

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as a mineral filler and natural sisal fiber as a stabilizing additive. The process begins with the selection of suitable input materials, followed by mix design, laboratory testing, performance evaluation, and finally the preparation of an optimized bituminous mix that provides improved pavement performance while promoting sustainability.

The first stage is Input Materials, where the essential components required for preparing the DBM mix are selected. These include coarse aggregates and fine aggregates conforming to MoRTH gradation specifications, 60/70 penetration grade bitumen as the binder, coal ash passing through a 75 µm sieve as the filler, and chopped sisal fibers of 15–20 mm length. These materials are chosen to improve the strength, durability, and environmental sustainability of the pavement.

The second stage is the Mix Design Process. Initially, all materials are selected according to the required standards, and the aggregates are blended to obtain the specified DBM gradation. Conventional Ordinary Portland Cement (OPC) is replaced with coal ash as the filler material to utilize industrial waste effectively. The bitumen content is varied between 5.0% and 6.0%, while the sisal fiber content is varied from 0% to 0.5% by the total weight of the mix. Marshall specimens are then prepared by compacting the mixture with 75 blows on each face, ensuring uniform specimen preparation for testing.

The third stage involves Testing and Evaluation. Marshall Stability tests are conducted to determine important engineering properties such as Marshall Stability, Flow Value, Bulk Density, Air Voids (Va), Voids in Mineral Aggregate (VMA), and Voids Filled with Bitumen (VFB). These parameters are analyzed to study the influence of varying bitumen and fiber contents on the overall performance of the pavement mix. Based on the experimental results, the Optimum Binder Content (OBC) and Optimum Fiber Content (OFC) are determined.

After optimization, the Optimum Mix is obtained by combining coal ash and sisal fiber at their optimum proportions. The optimized DBM mix exhibits higher Marshall Stability, lower flow values, improved durability, enhanced rutting resistance, better fatigue resistance, and full compliance with MoRTH specifications. The presence of sisal fibers creates a reinforcing network within the bituminous matrix, while coal ash improves filler performance and aggregate bonding.

The final stage represents the Outcome of the proposed system. The developed pavement mix offers an environmentally friendly, cost-effective, and high-performance alternative to conventional DBM mixes. By utilizing agricultural waste (sisal fiber) and industrial waste (coal ash), the system supports sustainable pavement construction while enhancing the structural performance and service life of flexible pavements.

The Key Benefits of the proposed architecture include effective utilization of natural fibers and industrial waste, reduced dependence on conventional cement fillers, lower construction costs, improved structural strength, enhanced pavement durability, and an eco-friendly approach to road construction. This integrated system provides a practical and sustainable solution for developing high-quality flexible pavements suitable for modern traffic conditions.

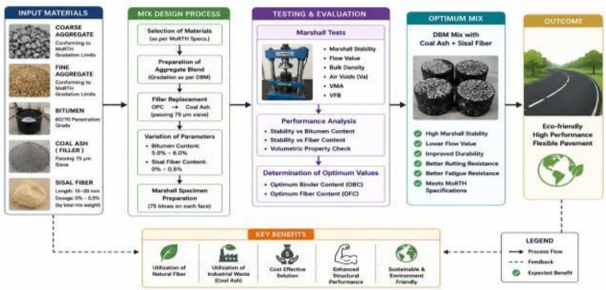

Fig 5.1: System Architecture

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Fig 6.1: **Agava sisalana plant**

Fig 6.2: **extracting the fiber from Sisal fiber plant**

Fig 6.3: **Sisal fiber (natural fiber)**

VII. CONCLUSION

This study concludes that the incorporation of natural sisal fiber and coal ash into Dense Bituminous Macadam (DBM) significantly enhances the engineering performance of flexible pavement mixes. Coal ash proved to be a suitable replacement for conventional Ordinary Portland Cement (OPC) as a mineral filler, while sisal fiber acted as an effective stabilizing additive by improving the internal reinforcement of the bituminous matrix. The modified mixes exhibited better mechanical and volumetric characteristics than the conventional DBM mix.

The Marshall Mix Design results identified an Optimum Binder Content (OBC) of 5.5% and an Optimum Fiber Content (OFC) of 0.3%. At these optimum values, the DBM mix achieved high Marshall Stability, a lower flow value, and satisfactory volumetric properties that comply with MoRTH specifications. The addition of sisal fiber enhanced resistance to rutting, fatigue cracking, and binder drain-down, while coal ash contributed to improved cohesion and load-bearing capacity.

Overall, the proposed DBM mix offers an economical, sustainable, and high-performance alternative for flexible pavement construction. By utilizing agricultural waste (sisal fiber) and industrial by-products (coal ash), the study promotes environmentally responsible road construction while improving pavement durability and reducing dependence on conventional construction materials. The findings demonstrate that the combined use of sisal fiber and coal ash can contribute to longer-lasting, cost-effective, and eco-friendly pavement infrastructure.

VIII. FUTURE SCOPE

The present study demonstrates the feasibility of using coal ash and natural sisal fiber in Dense Bituminous Macadam (DBM). However, further research can be carried out to improve the performance and broaden the practical applications of the proposed mix.

Investigate the long-term field performance of the modified DBM under different traffic loads and climatic conditions.

Evaluate additional engineering properties such as rutting resistance, fatigue life, moisture susceptibility, skid resistance, and dynamic modulus through advanced laboratory and field testing.

Study the influence of different natural fibers such as coir, jute, banana, bamboo, and hemp in comparison with sisal fiber.

Optimize the percentage and length of sisal fibers using statistical or machine learning optimization techniques to achieve maximum pavement performance.

Assess the performance of the modified mix using different grades of bitumen and polymer-modified binders.

Conduct comprehensive life-cycle cost analysis and environmental impact assessment to quantify the economic and sustainability benefits.

Explore the utilization of other industrial waste materials, such as fly ash, steel slag, silica fume, or waste plastic, in combination with coal ash.

Perform large-scale field trials to validate laboratory findings and evaluate the service life of the pavement under real traffic conditions.

Develop sustainable pavement design guidelines incorporating natural fibers and industrial by-products for future highway construction projects.

Investigate the recyclability and maintenance characteristics of the modified DBM mix to support long-term sustainable pavement management.

These future research directions build upon the study's objective of improving DBM performance while encouraging the use of environmentally friendly and cost-effective materials.

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