AMERICAN Journal of Engineering, Mechanics and Architecture
Volume 01, Issue 07, 2023 ISSN (E): 2993-2637

A Study on Impact of Bamboo Fiber on the Performance of Stone Matrix Asphalt with Slag as Aggregate Replacement

Onkar Yadav, Pappu Kumar, Ajay Kumar
Assistant Professor, Department of Civil Engineering, Sandip University, Sijoul, Madhubani-847235, Bihar, India

Ved Prakash Mishra
Research Scholar, Department of Civil Engineering, Sandip University, Sijoul, Madhubani-847235, Bihar, India

Abstract: Stone matrix asphalt (SMA) was initially developed in Germany in the 1960s and has since proven to offer numerous benefits in road surfacing. It provides enhanced resistance to permanent deformation, improved durability, longer service life, reduced ageing effects, high resistance to cracking, fatigue, and wear, improved skid resistance, and noise reduction. SMA is a gap-graded mixture of aggregates that maximizes the asphalt-cement content and incorporates coarse aggregate fractions. Its stability and resistance to rutting rely on the interlocking contact between aggregates, while the presence of a rich mortar binder contributes to its durability. To further enhance the performance of SMA, a naturally available and cost-effective stabilizer, namely bamboo fiber, has been used. Bamboo fiber is a cellulose fiber extracted from bamboo stems, possessing high strength in the fiber direction, excellent tensile, flexural, and impact strength, and thinness suitable for stabilization purposes. It is durable, exhibits tenacity, and offers good stability. This study explores the suitability of bamboo fiber in enhancing the stability and flow characteristics of Stone Matrix Asphalt Mixes, aiming to improve the overall performance of the mixture.

Keywords: Stone matrix asphalt (SMA), Road surfacing, Permanent deformation, Durability, Bitumen.

1. INTRODUCTION

Flexible pavement design is commonly preferred over rigid pavements in road pavement design due to its superior load carrying capacity, durability, resistance to wear and tear, and ability to withstand heavy loads. These desirable properties are primarily attributed to the surface bituminous pavement layer. This layer serves as a coating over the Stone Matrix Asphalt (SMA), which is a gap-graded mixture designed to provide strength through interlocking stone-to-stone contact. The properties of SMA are initially determined through laboratory testing to ensure maximum stability and optimal flow characteristics using the appropriate binder content. Stone Matrix Asphalt comprises approximately 70-80% coarse aggregate, 4-7% binder, 8-12% filler, and 0.3-0.5% fiber as a stabilizer. The coarse aggregate in the mixture facilitates stone-to-stone contact, enhancing resistance to rutting. The filler fills the voids between the aggregates, preventing tearing and wearing. The binder binds all the materials together, ensuring cohesion. The fiber acts as a stabilizer, increasing stability during high temperatures and preventing drainage during production, laying, and transportation.

2. CONVENTIONAL BITUMINOUS MIXES

The previous practices of using conventional Bituminous Mixes before the introduction of Stone Matrix Asphalt (SMA) were found to be less effective, leading to SMA completely overshadowing them. SMA has emerged as a superior alternative in various aspects. It offers enhanced resistance to rutting, especially in high-temperature conditions, and displays greater resistance to fatigue, resulting in increased durability. SMA also exhibits reduced sensitivity and improved moisture resistance, along with better crack resistance at low temperatures. Furthermore, SMA demonstrates superior performance in terms of resisting plastic deformation compared to conventional Bituminous Mixes. Considering these advantages, SMA has proven to be a preferable choice and has garnered increased attention and interest.

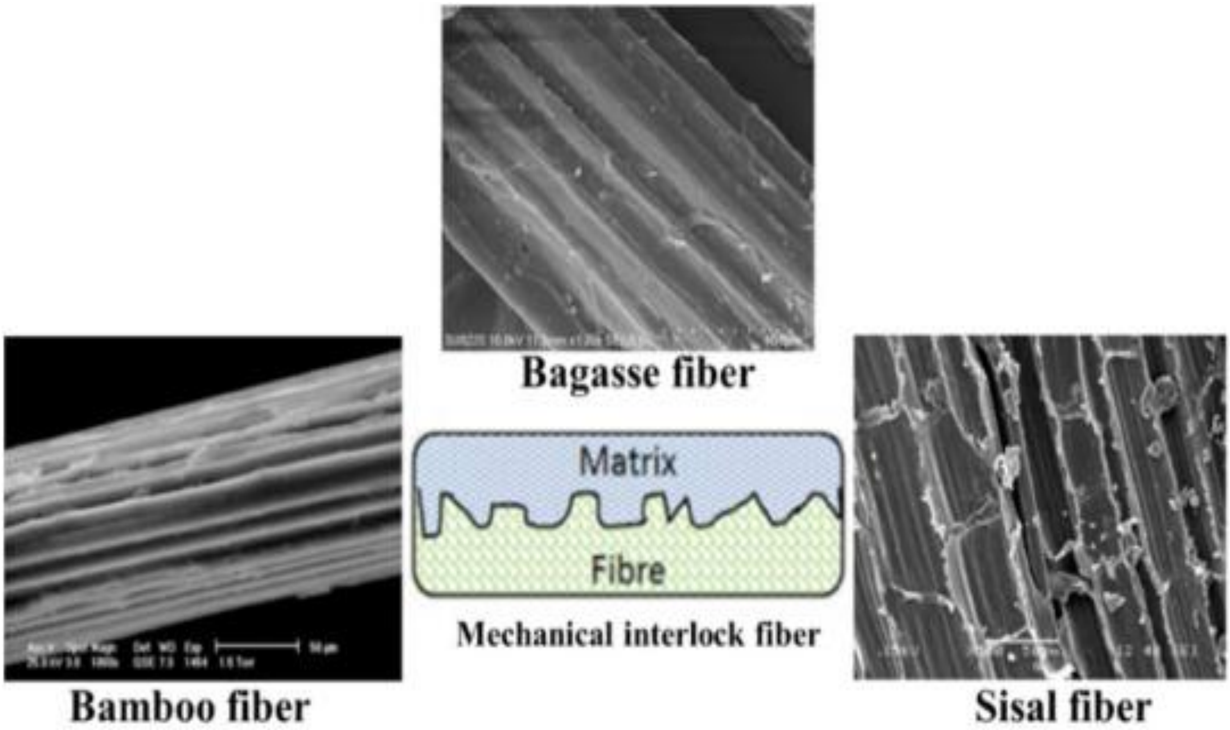

Fig. 8. SEM images of plant fibers (Amiandamhen et al., 2020; Kar et al., 2019; Khalil et al., 2012)

3. ADVANTAGES OF USING BAMBOO FIBERS

The study on the impact of bamboo fiber on the performance of Stone Matrix Asphalt (SMA) with slag as aggregate replacement offers several advantages.

- Enhanced Stability: The incorporation of bamboo fiber in SMA improves the stability of the mixture. The fibers act as stabilizers, increasing the interlocking between the aggregates and improving the overall stability of the asphalt pavement. This results in a more robust and durable road surface.
- Increased Flow Value: Bamboo fiber helps to enhance the flow value of the SMA mixture. It improves the workability and ease of compaction during the construction process. This ensures better placement and compaction of the asphalt mixture, leading to a smoother and more uniform road surface.
- Improved Mechanical Properties: The addition of bamboo fiber contributes to the improved mechanical properties of the SMA. It enhances the tensile strength, flexural strength, and impact resistance of the asphalt mixture. This leads to increased resistance against cracking, rutting, and fatigue, enhancing the overall performance and longevity of the road pavement.
- Sustainable Solution: Bamboo fiber is a natural and renewable material. Its utilization as a stabilizer in SMA offers environmental benefits by reducing the dependency on non-

renewable resources. It provides a more sustainable and eco-friendly approach to road construction.

- Cost-Effective Option: Bamboo fiber is relatively cost-effective compared to other non-conventional fibers. Its use in SMA can help reduce the overall material costs without compromising the performance and durability of the asphalt mixture. This makes it a viable and economical solution for road pavement construction.

4. LITERATURE REVIEW

Conducting a comprehensive survey is crucial when undertaking project works, research studies, or any innovative endeavors. It serves as a vital starting point, providing a foundational understanding of the topic of interest and revealing previously conducted works that might otherwise go unnoticed. Surveys help in gaining insights into past research, exploring the outcomes, and drawing inspiration for further investigations. In the case of this particular topic, the survey focuses on Stone Matrix Asphalt, encompassing aspects such as mix preparation, properties, materials, and its applications. Additionally, the introduction of Bamboo Fiber as a novel element in the research adds value by drawing upon previous studies to identify various properties and characteristics associated with this fiber. By conducting a thorough survey, a solid knowledge base is established, fostering progress and encouraging advancements in the chosen field.

Chen et al. (2016) The limited availability and high cost of natural stone aggregate have led to the exploration of alternative materials such as steel slag. In this study, asphalt mixtures incorporating basic oxygen furnace (BOF) steel slag as coarse aggregate were investigated for their engineering properties. Laboratory tests revealed that the addition of steel slag resulted in asphalt mixtures with excellent resistance to permanent deformation and moisture-induced damage. The angular and rough texture of the steel slag particles contributed to an enhanced interlocking mechanism and favorable mechanical properties. Subsequently, a test road was constructed using three different types of asphalt mixtures: stone mastic asphalt with BOF (SMA-BOF), dense-graded asphalt concrete with BOF (DGAC-BOF), and dense-graded asphalt concrete with natural aggregate (DGAC-NA). The SMA-BOF section exhibited the lowest rut depth, even under high-stress conditions caused by vehicle braking, accelerating, and turning. Pavement performance surveys were conducted at regular intervals, and the ride quality and friction characteristics of the BOF sections were found to be comparable to or better than those of the section constructed using natural aggregate. Field data collected over a three-year period demonstrated that the utilization of steel slag as a surface course aggregate in areas with heavy braking and cornering maneuvers resulted in minimal rutting, cracking, or other significant failures. The test results indicate that using steel slag as a substitute for coarse aggregate in surface courses is technically viable and appropriate.

Zhao et al. (2016) The main goal of this study was to assess the functional performance of asphalt mixtures incorporating basic oxygen furnace (BOF) slag coarse aggregate (BSCA) obtained from an industrial production line. The results indicated that the asphalt mixture containing BSCA exhibited superior durability, suggesting that the quality of BSCA obtained from industrialized production lines was well controlled. This finding suggests that BSCA can be effectively utilized in entity engineering projects, with confidence in its performance and suitability.

Alnadish et al. (2018) The objective of this study was to assess the performance of asphalt mixtures by replacing natural coarse aggregate with electric arc furnace (EAF) steel slag aggregate, while incorporating aramid fiber to reduce asphalt layer thickness and transportation costs. The steel slag aggregate underwent a water immersion process to minimize free lime and free magnesia content, which could cause expansion. Six different mixtures with varying proportions of aramid fiber were evaluated. Thermogravimetric and XRD tests were conducted to analyze the benefits of treating the steel slag aggregate, while resilient modulus and dynamic creep tests were performed on the mixtures. Response Surface Methodology (RSM) was utilized to analyze the results and investigate the interaction between factors and responses. The mechanistic empirical pavement design approach was employed to assess the potential for extending the service life or reducing the thickness of the asphalt layer. The results demonstrated that the treatment of steel slag was effective in reducing free lime and free magnesia content. Introducing 0.05% aramid fiber by weight into the mixture significantly increased the resilient modulus and dynamic creep, making it the optimum content for the mixture. This study suggests that incorporating steel slag aggregate and aramid fiber in ultra-thin asphalt overlays can improve the service life of existing asphalt layers.

Ravindraraj et al. (2018) The utilization of asphalt materials and mixtures initially originated and gained popularity in European countries and North America. One such mixture is Stone Matrix Asphalt (SMA), which is characterized by its gap-graded composition comprising a high proportion of coarse aggregates, increased asphalt content, and the inclusion of fiber additives as stabilizers. In this particular study, the focus was on investigating the engineering properties of SMA mixtures with and without the addition of a non-conventional natural fiber, specifically banana fiber. Laboratory tests were conducted to assess the suitability of banana fiber as a stabilizing agent in the mixture. The tests included analyzing flow parameters, stability, and mechanical properties of the mixture. The aggregate gradation in the SMA mix adhered to the specifications outlined by the Ministry of Road Transport and Highways (MoRTH). The binder content ranged from 4% to 7% by weight of the aggregate, while the fiber content was set at 0.3% by weight of the aggregate. Cement was used as the filler material, and a 60/70 grade bitumen served as the binder.

Karthik et al. (2019) Asphalt pavement is widely used in highways due to its numerous advantages, such as low noise, good skid resistance, convenience, and recyclability. However, repeated vehicle loading and freeze-thaw cycles can cause distress in asphalt pavement, leading to cracking and rutting. To address these issues and enhance pavement performance, Stone Matrix Asphalt (SMA) has been developed and modified. SMA is a gap-graded Hot Mix Asphalt (HMA) designed to minimize deformation and improve rutting resistance and durability. It achieves this by relying on the structural integrity of stone-to-stone contact, with the aggregate properties playing a crucial role in resisting rutting, rather than solely relying on the properties of the asphalt binder. SMA was first introduced in Europe around 1990 to combat rutting and studded tire wear, and it has proven effective in improving various engineering properties of asphalt mixtures, including viscoelasticity, dynamic modulus, moisture susceptibility, creep compliance, and rutting resistance. In the modification of SMA, fiber additives are incorporated to further enhance its performance and reduce rutting failures in asphalt pavement. These fiber additives can include cellulose fibers, lignin fibers, and polyester fibers. In this particular research, a non-conventional natural fiber, namely banana bamboo fiber, was used as the fiber stabilizer. Banana fiber is a polyester fiber known for its high thermal resistance. The SMA mixtures in this study were designed based on the specifications provided by the Ministry of Road Transport and Highways (MoRTH). The binder content varied from 4% to 7% by weight of the aggregate, while the fiber content was set at 0.3% by weight of the aggregate. A 60/70 grade bitumen was used as the binder material.

Razahi et al. (2020) This experimental investigation focused on studying the improvement in properties of Stone Matrix Asphalt (SMA) by incorporating sisal fiber and coir fiber as additives. Regardless of the fiber type, the SMA mixtures exhibited maximum stability, flow value, Marshall Quotient, bulk-specific gravity, and volumetric properties at a fiber content of 0.3%. The SMA mixtures with coir fiber demonstrated the highest stability (16.229 kN) compared to sisal fiber-stabilized mixtures (15.24 kN), indicating superior resistance to rutting and overall performance compared to the blends with sisal fiber. The stability increase in the coir fiber mixtures was approximately 23% compared to the control mixture, while the increase in the sisal fiber mixtures was around 16%. The addition of fibers resulted in a decrease in the flow value of the SMA mixtures, making them less flexible due to the rigidity of the fibers within the mixture.

The Marshall quotient of the 0.3% coir fiber-stabilized SMA mixture was approximately 40% higher than the control blend, and for the sisal fiber mixture, it was nearly 32% higher. This indicates improved resistance to permanent deformation, making these blends suitable for applications where a strong bituminous mixture is required. The bulk specific gravity of the coir fiber and sisal fiber mixtures at 0.3% fiber content was found to be the same, with a value of 2.313.

Bishow et al. (2020) In this study, the researchers compared the Marshall properties of Asphalt mixtures containing stone dust filler with those containing steel slag filler. Typically, cement, limestone, and stone dust filler materials are commonly used in Asphalt Pavement Construction in Nepal. However, the researchers investigated the potential of utilizing steel slag, a by-product of the steel-making industry, as a filler material in Asphalt mixes. They prepared a total of 63 Marshall specimens, with varying steel slag content (ranging from 2% to 8%), and 15 specimens with stone dust filler. The results of the study indicated that incorporating steel slag in Asphalt Concrete mixtures can improve the Marshall properties of the mixtures. The use of steel slag as a filler material was found to be suitable within the range of 2% to 8% content, as it met the specifications of the Department of Roads. Notably, the Asphalt mixtures containing 4% steel slag content demonstrated the best performance across all the evaluated Marshall properties.

Xia et al. (2021) The study demonstrated that incorporating plant fibers, specifically bamboo fibers, can effectively enhance the durability of asphalt mixtures. Bamboo fiber modified asphalt mastic exhibited desirable qualities such as good ductility and adhesion, attributed to its rough surface and excellent oil absorption performance. When compared to lignin fiber asphalt mixtures, bamboo fiber asphalt mixtures showcased improved and more consistent low-temperature aging durability and moisture aging durability, although their mechanical properties were slightly weaker. Both fiber types demonstrated similar benefits in enhancing the freeze-thaw cycle durability of asphalt mixtures. Bamboo fiber contributed to increased flexibility and delayed crack development, resulting in improved fatigue durability of the mixture. The durability of stone mastic asphalt (SMA) gradation mixtures surpassed that of asphalt concrete (AC) gradation. The material composition and aggregate gradation of plant fiber asphalt mixtures greatly influenced their durability. Future research should focus on establishing a comprehensive evaluation system that considers fiber type, fiber properties, mixture gradation, and durability to facilitate targeted regulation of the durability of different fiber asphalt mixtures. Bamboo fiber proved to be a reliable alternative to lignin fiber, and further investigation can explore methods to enhance its surface properties and promote uniform dispersion within the asphalt mixture.

Masri et al. (2021) The objective of this study was to address the issue of excessive binder drain down in Stone Mastic Asphalt (SMA) by incorporating bamboo fiber as a modified binder. Bamboo fiber was selected for its cost-effectiveness compared to conventional fibers. The study aimed to evaluate the mechanical performance of bamboo fiber-modified SMA 20 by conducting tests on Marshall stability, resilient modulus, dynamic creep, and Cantabro Loss. Twelve samples of SMA 20 mix with PEN 60/70 binders were tested for each parameter, with varying bamboo fiber content ranging from 0% to 0.6% of the aggregate weight. The results demonstrated that the addition of 0.4% bamboo fiber yielded the lowest values for abrasion and dynamic creep, while also providing the highest values for resilient modulus, stability, density, and stiffness. Therefore, the optimal fiber content for design purposes was determined to be 0.4%. Consequently, it can be concluded that the inclusion of bamboo fiber enhances the performance of SMA 20.

Ahmed et al. (2022) The objective of this study was to examine the impact of bamboo fiber and sugarcane bagasse fiber on the mechanical properties of Hot Mix Asphalt (HMA) production. The research followed an experimental design methodology, and samples were collected using non-probability sampling techniques. The preparation of asphalt mixture specimens for asphalt mix design adhered to the standards specified by AASHTO, ASTM, and EN. Various tests including aggregate tests, Bitumen test, Marshall test, Indirect Tensile Strength test, and Rutting Test (RT) were conducted to compare the performance of bamboo fiber and sugarcane bagasse fiber as modifiers in HMA production. Crushed stone coarse aggregate, fine aggregate, mineral fillers, and 60/70 bitumen were used to prepare HMA mixes, with the addition of bamboo and sugarcane bagasse fibers as additives. The bitumen content ranged from 4.5% to 6%, while the fiber additives ranged from 0.2% to 0.5% of the total weight of the sample. The laboratory results were then compared to the specified standards. The optimal content for both fibers was found to be 0.3%, while the optimal bitumen content was 5.2% for open-graded asphalt concrete (OAC) and 4% for open-graded modified friction course (OMF). This suggests that the inclusion of both bamboo fiber and sugarcane bagasse fiber in asphalt concrete mixtures enhances the performance of asphalt pavements in resisting external loads. Specifically, at 0.3% content, both fibers significantly improve asphalt marshal stability, Indirect Tensile Strength (ITS) of HMA, and rutting resistance of asphalt concrete (AC).

Liu et al. (2022) This study aimed to assess the impact of two dosages of slag aggregate replacement on the performance of asphalt concrete. Lab tests and in situ test sections were conducted to evaluate the effect of coarse grain slag from the basic oxygen furnace (BOF6 and BOF3) and fine grain slag from the tilted rotary drum (TRD) on the asphalt concrete mixture. Two dosages, BOF6 + BOF3 and BOF3 + TRD, were used, with BOF6 + BOF3 having a higher proportion of coarse-grained BOF particles and BOF3 + TRD containing more fine-grained TRD particles. The unit weight of the BOF3 + TRD mixture was found to be higher than that of the BOF6 + BOF3 mixture with similar asphalt content. The BOF6 + BOF3 mixture exhibited superior mechanical properties, including resilient modulus, static creep, dynamic creep, residual strength, and rut resistance, compared to the BOF3 + TRD mixture. This can be attributed to the higher content of coarse-grained BOF in the BOF6 + BOF3 mixture. However, the BOF3 + TRD mixture demonstrated better heat conduction among aggregates, improved long-term skid resistance, and a more uniform distribution of thermal characteristics. In conclusion, the replacement of aggregate with mixed slag can enhance the performance of asphalt concrete pavement, but the dosage should be carefully considered to meet specific performance requirements.

Kumar et al. (2023) The experimental investigation conducted on bituminous mixes, including Stone Matrix Asphalt (SMA) and Bituminous Concrete (BC), led to the following findings. All three types of fillers used in BC met the necessary specifications, demonstrating their suitability for application. Among the fillers, BC with cement filler exhibited the highest stability, while fly ash and stone dust fillers proved to be viable and cost-effective alternatives. The addition of fibers up to 0.3% improved the stability of BC, although further fiber incorporation did not yield significant stability enhancements compared to SMA. The inclusion of fibers resulted in a decrease in the flow value of BC, but when 0.5% of fibers were added, the flow value increased. SMA displayed superior tensile strength compared to BC, and the introduction of fibers reduced deformation in both types of mixes. Notably, SMA with sisal fiber demonstrated excellent performance for flexible pavement applications, indicating its potential in construction projects.

G M, Naveen. (2023) This article examines the laboratory performance of asphalt mixtures containing electric arc furnace slag (EAF) and basic oxygen furnace (BOF) slag as partial replacements for conventional aggregates at varying percentages (10%, 30%, and 50%). The study analyzes the surface morphology and chemical composition of aggregates using SEM and EDAX analysis. Various mix design properties of the asphalt mixtures, including abrasion loss, moisture sensitivity, rutting resistance, fatigue behavior, and resilient modulus, are investigated. The results demonstrate that the mix design properties of asphalt mixtures incorporating EAF and BOF slag meet the requirements. Additionally, the inclusion of EAF and BOF slag reduces abrasion loss regardless of the replacement percentage. Asphalt mixtures with 30% EAF slag exhibit higher moisture sensitivity, rutting resistance, fatigue behavior, and resilient modulus compared to those with 30% BOF slag and conventional mixtures. However, asphalt mixtures with 50% replacement of EAF and BOF slag perform lower than control mixtures. The optimal replacement percentage for EAF and BOF steel slag is determined to be 30% of conventional aggregate. Furthermore, EAF steel slag outperforms BOF steel slag in terms of moisture sensitivity, rutting resistance, fatigue behavior, and resilient modulus. The findings of this study provide valuable insights for the development of recycled asphalt mixtures utilizing slag aggregates derived from the steel industry.

Kumar et al. (2023) The utilization of manufactured sand in concrete offers several beneficial effects on its performance. In both M40 and M50 grade concretes, when manufactured sand is used, there is a noticeable reduction in water absorption compared to conventional sand concrete. This reduction in water absorption is achieved by employing a lower water-binder ratio, resulting in concrete that is impermeable and more resistant to water penetration. Furthermore, the inclusion of manufactured sand leads to a decrease in chloride ion penetrability, indicating improved durability and lower permeability of the concrete. Another advantage of using manufactured sand is its enhanced resistance to acid and alkaline attacks, resulting in reduced weight loss compared to concrete made with traditional sand. Additionally, concrete mixes incorporating synthetic sand demonstrate improved resistance to impact and abrasion, making them more resilient in challenging conditions. Overall, the incorporation of manufactured sand positively influences various aspects of concrete performance.

Haibin et al. (2023) This study focuses on recycling bamboo fibers derived from bamboo residue to enhance the performance of asphalt mixtures, aiming to utilize bamboo waste effectively. Initially, the research evaluates and analyzes the fundamental performance parameters of sinocalamus affinis fiber, phyllostachys pubescens fiber, and green bamboo fiber, determining their optimal content and length. Subsequently, the mix ratio design of bamboo fiber modified asphalt mixture is formulated using the response surface method, and the rationality of the mix ratio is verified. Finally, mixture specimens are prepared based on the experimental design mix ratio, and the high temperature, low temperature performance, and moisture susceptibility of the bamboo fiber modified asphalt mixtures are tested. The results indicate an improvement in high temperature performance, low temperature performance, and moisture susceptibility of the bamboo fiber modified asphalt mixtures compared to SBS modified asphalt mixtures. Optimal road performance is achieved when using bamboo fibers with a length of 7.25 mm and a content of 0.22%. Consequently, the decomposition of bamboo residue into bamboo fiber and its application in asphalt pavement contribute to enhanced utilization of bamboo waste, offering notable environmental benefits and substantial promotion potential.

5. SUMMARY

The review highlights that the inclusion of waste glass in concrete bricks can improve their thermal insulation, reduce energy consumption, and enhance their aesthetic appeal. Additionally, waste glass exhibits pozzolanic properties, contributing to the strength and durability of the concrete matrix. However, challenges related to alkali-silica reaction (ASR) and the need for appropriate glass particle size distribution need to be addressed. Furthermore, the incorporation of optical fibers in concrete bricks offers unique advantages, including light transmission, enhanced aesthetics, and potential applications in smart infrastructure. However, issues such as fiber dispersion, orientation, and compatibility with the cement matrix require further investigation. The review paper concludes that the utilization of waste glass and optical fibers as aggregates in the production of concrete bricks holds significant potential for sustainable construction practices. The inclusion of these waste materials can address waste management issues, reduce the carbon footprint, and enhance the performance and aesthetics of concrete structures. However, further research is needed to optimize the mixture proportions, address compatibility issues, and evaluate the long-term performance of such concrete bricks. The findings from this review can serve as a basis for future research and development in this field, promoting the adoption of eco-friendly practices in the construction industry.

REFERENCES

1. Chen, Jian-Shiuh & Wei, Shih-Hsiu. (2016). Engineering properties and performance of asphalt mixtures incorporating steel slag. Construction and Building Materials. 128. 10.1016/j.conbuildmat.2016.10.027.
2. Kumar, A. and Yadav, O., 2023. Concrete Durability Characteristics as a Result of Manufactured Sand. Central Asian Journal of Theoretical and Applied Science, 4(3), pp.120-127.
3. Kumar, A., Yadav, O. and Kumar, A.N., A REVIEW PAPER ON PRODUCTION OF ENVIRONMENT FRIENDLY CONCRETE BY USING SEWAGE WATER. International Journal of Creative Research Thoughts (IJCRT), ISSN, pp.2320-2882.
4. Kumar, A. and Bohara, J., A REVIEW REPORT ON INFLUENCE OF FIBER ADDITION ON THE MECHANICAL AND DURABILITY CHARACTERISTICS OF NO-FINES CONCRETE.
5. Kumar, A. and Nirala, B., 2023. Studies on Strength and Durability of Concrete Made with Manufactured Sand. Studies, 7(2).
6. Kumar, S.R. & Ravindraraj, B.J.. (2018). Laboratory investigation on stone matrix asphalt using banana fiber. International Journal of Civil Engineering and Technology. 9. 1263-1268.
7. Karthik, Avula & Nababu, N. (2019). International Journal of Research Cellulose Fibers (Banana Fibers) As A Stabilization Additive In Stone Matrix Asphalt. International Journal of Research. 06. 423-427.
8. Razahi, Mustafa & Chopra, Avani. (2020). An Experimental Investigation of Using Sisal Fiber and Coir Fiber as An Additive in Stone Matrix Asphalt. 5111-5128.
9. Kumar, N. ., Kumar , P. ., Kumar, A. ., & Kumar, R. . (2023). An Investigation of Asphalt Mixtures Using a Naturally Occurring Fibre. AMERICAN JOURNAL OF SCIENCE AND LEARNING FOR DEVELOPMENT, 2(6), 80–87. Retrieved from http://inter-publishing.com/index.php/AJSLD/article/view/1977.
10. Kumar, A., & Yadav, O. (2023). Concrete Durability Characteristics as a Result of Manufactured Sand. Central Asian Journal of Theoretical and Applied Science, 4(3), 120-127. https://doi.org/10.17605/OSF.IO/8P5HE.
11. Kumar, P. and Alam, M.F., Seismic Analysis of RC Building with Steel Bracing.
12. Jha, S.K., Prakash, C. and Kumar, A., 2022. Design and Synthesis of Polymer Nano Composite Enamel for Improvement in Weathering and Corrosion Resistance.
13. Kumar, A. and Kadian, A., 2022. Research on Strength and Durability of Concrete Manufactured with Artificial Sand.
14. Kumar, A. and Kadian, A., Concrete Strength Characteristics as a Result of Artificial Sand.
15. Liu, Pei & Lin, Deng-Fung & Wang, Wei-Jhu. (2022). Effect of mixed slag aggregate replacement on performance of asphalt concrete. Journal of Material Cycles and Waste Management. 24. 10.1007/s10163-022-01398-6.
16. Kumar, A., & Yadav, O. (2023). Concrete Durability Characteristics as a Result of Manufactured Sand. Central Asian Journal of Theoretical and Applied Science, 4(3), 120-127. https://doi.org/10.17605/OSF.IO/8P5HE.
17. Kumar, N. ., Kumar , P. ., Kumar, A. ., & Kumar, R. . (2023). An Investigation of Asphalt Mixtures Using a Naturally Occurring Fibre. AMERICAN JOURNAL OF SCIENCE AND LEARNING FOR DEVELOPMENT, 2(6), 80–87. Retrieved from http://inter-publishing.com/index.php/AJSLD/article/view/1977.

18. Kumar, N., Kumar, P., Kumar, A. and Kumar, R., American Journal of Science and Learning for Development.

19. Kumar, R., Kumar, P. and Yadav, O., 2023. Experimental Study on Hot Bituminous Mix. *World of Science: Journal on Modern Research Methodologies*, *2*(5), pp.48-53.

20. Jha, A. K., Yadav, O. ., Kumar, P. ., & kumar, A. . (2023). Evaluation of Binding Properties of Bituminous Pavement Layers. *AMERICAN JOURNAL OF SCIENCE AND LEARNING FOR DEVELOPMENT*, *2*(5), 3–8. Retrieved from http://inter-publishing.com/index.php/AJSLD/article/view/1616.

21. Kumar, A., Yadav, O. and Shukla, R., 2023. A COMPREHENSIVE REVIEW PAPER ON PARTIAL CEMENT SUBSTITUTION IN CEMENT MORTAR WITH WOOD ASH. Research in Multidisciplinary Subjects, 1, p.26.

22. Kumar, N., Kumar, P., Kumar, A. and Kumar, R., 2023. An Investigation of Asphalt Mixtures Using a Naturally Occurring Fibre. AMERICAN JOURNAL OF SCIENCE AND LEARNING FOR DEVELOPMENT, 2(6), pp.80-87.

23. Kumar, A., 2023. WEB OF SYNERGY: International Interdisciplinary Research Journal

24. Ajay Kumar and Sujeet Kumar (2023) “Review Paper on Assessment of Deterioration in Concrete Filled with Steel Tubular Section via Guided Waves”, World of Science: Journal on Modern Research Methodologies, 2(8), pp. 12–19. Available at: https://univerpubl.com/index.php/woscience/article/view/2444 (Accessed: 8 August 2023).

25. Ajay Kumar,Onkar Yadav,Sagar Kumar, "AN OVERVIEW ARTICLE ON INCORPORATING HUMAN HAIR AS FIBRE REINFORCEMENT IN CONCRETE", International Journal of Creative Research Thoughts (IJCRT), ISSN:2320-2882, Volume.11, Issue 6, pp.e967-e975, June 2023, Available at :http://www.ijcrt.org/papers/IJCRT2306566.pdf