A Review on Evaluating SMA for Durable Pavements by Using Different Stabilizing Additives

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Abstract

The study investigates the incorporation of natural fibers into stone matrix asphalt (SMA) mixtures, focusing on their mechanical performance and sustainability. Various types of natural fibers, including coconut, sisal, and textile waste, are evaluated for their effects on the durability and structural integrity of SMA. The research synthesizes findings from multiple studies, highlighting the advantages of fiber reinforcement in enhancing resistance to deformation and cracking under load. Additionally, it addresses the environmental benefits of utilizing waste materials in asphalt production, contributing to sustainable construction practices. The results indicate that fiber-modified SMA not only improves performance characteristics but also promotes resource conservation by repurposing agricultural and industrial by-products. This extensive study shows that regular fibers can be effective additives in asphalt technology, paving the way for more sustainable road construction solutions.

Key Words: SMA (Stone Matrix Asphalt), asphalt mixtures , coconut fibers, cellulose fibers and mechanical properties, steel slag.

1. Introduction

The use of natural fibers in stone matrix asphalt (SMA) as part of the blend has become a focus during the last few years with two main goals of improving the mechanical strength of the asphalt mixtures and environmentally friendly construction. Studies show that the addition of natural fibers like coconut, sisal, and even waste material has a positive impact on the SMA performance limitations, durability and deformation under load resistance in particular. For example, Putman and Amirkhanian (2004) investigated the use of waste fibers in SMA mixtures and presented that these additives can greatly facilitate the recycling of materials and at the same time improve the properties of the mixture [1].

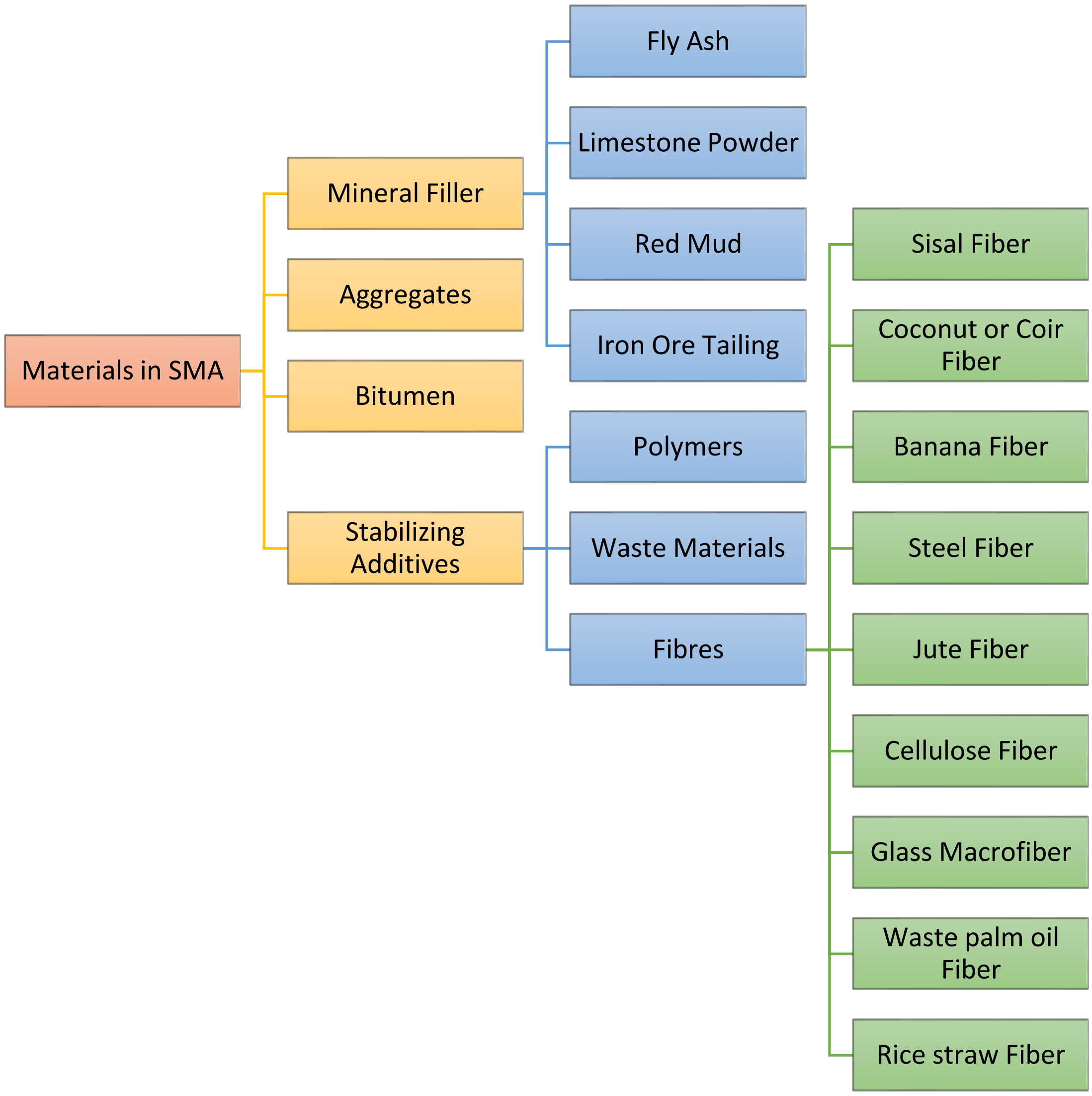
Including natural fibers into SMA enhances its sustainability and mechanical strength claim Kumar and Ravitheja (2019) while also remarking upon the many benefits that can be achieved as a result of their work [2]. This work is also supported by Sheng et al (2017) as they also assert that fibers MMC or 'SMA' maintains its performance even when exposed to a plethora of diverse conditions [3].

Vale et al., (2014) as cited by Holt, have placed incredible emphasis on the selection of fiber types and design strategies [4]. This ensures the usage of fibers in SMA mixtures is fruitful. Further, there is growing corpus of evidence that has been suggesting that as the pavement engineering and technology evolves they become environmentally sustainable as more and more students focus onto the utilization of natural and recycled materials in asphalt. Therefore, the purpose of this literature review will be to collate the existing data and research on fiber-modified SMA, focusing on the different fiber types available, along with their specified performance characteristics or metrics and finally where the research in this in the future.

2. Advantages of SMA

Stone Mastic Asphalt (SMA) provides a tough, durable, and rut-resistant wearing course, making it especially suitable for high-traffic areas. SMA has very high stability against permanent deformation (rutting) as well as exceptional wear resistance. Besides these, SMA is slow in aging and crack-resistant; hence service life is lengthy. macro-texture that increases friction but simultaneously reduces noise generation and also minimizes spray generation as well as hydroplaning effects compared to dense-graded pavements.

SMA is especially applicable in very stress-laden locations, like intersections where vehicular loads are extremely heavy. The only drawback compared to conventional hot mix asphalt is the increased cost associated with mineral fillers, fibers, modified binders, and possibly increased asphalt content. These costs are certainly upfront; however, the long-term benefits—reduced maintenance and increased durability—often justify the expense [6].



3. Materials in Stone matrix asphalt (SMA)

3.1 Bitumen

Stone Matrix Asphalt (SMA) uses a larger quantity of polymers compared to other mixes, it also requires the use of various mixes such as fillers and stabilizing additives to ensure better performance on roads. This is why several researches have tried incorporating different grades of bitumen into SMA. However, using modified bitumen further increases performance. According to IRC norms, the appropriate amount of bitumen in SMA is the quantity where the pavement stands at an air void of 4%. The reinforce the formulation of the provided asphalt [5].

3.2 Aggregates

Some mixing processes, such as simple mixing aggregates or SMA, are particularly sensitive to the characteristics and quality of aggregates in order to provide good resistance against caries. The aggregate mixture's stability needs to be ensured to achieve the ideal design. The coarse aggregates are required to be clean, hard, durable, and preferably cubical in shape. They should also be devoid of dust, soft organic matter, and any other contaminants. Such selection and treatment of aggregates improve the quality and durability of the SMA since it is designed to withstand wear and deterioration during service.

i. Aggregates need to have sufficient hardness not to break when subjected to high traffic loads.
ii. They should possess high polishing resistance to prevent the loss of texture and control.
iii. Aggregates must have good resistance to abrasion so that they can last a long time.
iv. The aggregates should be coarse and cuboidal-shaped for easy movements and stain resistance.

Aggregates gradation is selected from MORTHs Specifications [5,6].

Table -1: Gradation of Aggregate for SMA

SMA Determination	19mm SMA
Course where used	Binder (intermediate) course
Nominal aggregate size	19mm
Thickness of layer	45-75mm
Indian Standard sieve (mm)	% of aggregate passing from each sieve
26.5	100
19	90-100
13.2	45-70
9.5	25-60
4.75	20-28
2.36	16-24
1.18	13-21
0.60	12-18
0.30	10-20
0.075	8-12

3.3 Mineral Filler:

The importance of mineral fillers cannot be overstated, as they are important in the composition. For instance, rock powders, slag powders, blended cements, and slaked limes are classified under Mineral fillers. These fillers are effective in increasing the stiffness of the asphalt matrix and helping to alleviate drainage and rutting issues. Different fillers can be used to optimize the SMA formulation and enhance pavement performance[6]

3.3.1 Fly Ash

Fly ash is a fine grey powder produced from the burning of coal at power plants. It consists mainly of very small, spherical particles swept away with the flue gases during the burning process.

3.3.2 Limestone Powder

Limestone powder, which is prepared from sedimentary rock limestone, mainly consists of calcium carbonate. The material shows excellent application in various industries due to its useful properties.

3.3.3 Red Mud

It is usually termed red mud or even bauxite residue-a by-product generated through the Bayer process in the course of alumina extraction from the ore of bauxite. Simple breakdown of what red mud is and its importance.

3.3.4 Iron Ore Tailings

Iron ore tailings (IOT) represent the waste generated in iron ore mining and processing. During iron ore extraction, it usually contains both valuable minerals and gangue (unwanted materials). In such a case, the value portion is filtered out, and the remaining portion is termed as tailing.

3.4 Stabilizing Additives

SMA uses fibers as stabilizers to develop other performance improvements due to reductions in binder drain down and/or improved rut resistance. Fibers commonly used in SMA include natural fibers such as coconut, hemp, sisal, and coir, with synthetic fibers such as jute also being used. There is greater potential for binder separation during production due to the gap-graded nature of SMA, and hence, these stabilizers become quite necessary. Fibers such as cellulose, mineral, and polymers provide excellent prevention of drainage apart from mechanical stability and resistance to cracking. Several studies have investigated the performance of these fibers in optimally designing SMA mixtures to improve durability and other performances [5,6].

3.4.1 Polymer

Polymer stabilizers are the special chemical additives found in plastics and rubber to act against deterioration in processing and during use. These additives offer protection against environmental factors, including heat, light, and oxygen.

3.4.2 Waste Materials

Waste materials can be incorporated in Stone Matrix Asphalt (SMA) in order to replace the natural aggregates which can further reduce the negative effects on the environment. The types of wastes are construction waste, plastics, agricultural wastes, and many more, which enhance the performance of asphalt mixtures. Incorporation of waste in SMA also brings cost-effective solutions to construct roads besides waste management. This approach supports sustainability by conserving natural resources and reducing landfill waste while maintaining the durability and strength of the asphalt pavement.

3.4.3 Fiber

Fiber stabilizing additives are critical ingredients in Stone Matrix Asphalt (SMA) mixes to improve their performance and longevity. The fibers are employed to avoid binder drain-down, enhance stability, and strengthen the mechanical characteristics of the asphalt mix. There are different sorts of strands utilized as part a part of SMA blends like Sisal Fiber, Coconut or Coir Fiber, Banana Fiber, Steel Fiber, Jute Fiber, Cellulose Fiber, Glass Macro fiber, Waste palm oil Fiber, Rice straw Fiber [1]

3.4.3.1 Sisal Fiber

Sisal plantations in India produce yield approximately 2.5 tonnes of dry fiber per hectare annually. The sisal is extracted from the leaves of the sisal plant in a process referred to as decortication, which is carried out using a machine known as a Respaded. Sisal is a leaf fiber that comes from the Agave sisal plant [1] [Fig. 1].

Fig. 1 Sisal Fiber

3.4.3.2 Coconut or Coir Fiber

Coir fiber is a natural fiber that comes from coconut fruits, obtained mainly from coconut palms. This widespread fiber, especially in the tropics, is derived from the tissue of mature coconut mesocarp. Coir fibers have thick cellulose walls and a higher lignin ratio, rendering them strong and rough, though less pliable than some fibers such as cotton or flax. They are comparatively waterproof and are classified into two species: white and brown, with the latter having a higher lignin content. They are extracted by soaking coconuts for three months to break down the fibres [1,5,0] [Fig. 2].

Fig. 2 Coconut or Coir Fiber

3.4.3.3 Banana Fiber

Banana fiber is a highly valuable material with strength and durability, thereby much in demand in the market. Every year, lots of biowaste is generated from banana farming, which has to be disposed of in a suitable manner. With the retrieval of banana fiber, banana farmers can utilize the waste effectively, generating more income for them. Banana fiber needed for this activity was sourced from Kerala Agricultural University [1] [Fig. 3].

Fig. 3 Banana Fiber

3.4.3.4 Steel Fiber

Steel fiber is used more and more in Stone Matrix Asphalt (SMA) to improve its performance properties. SMA is durable and resistant to deformation and is thus well adapted for heavy traffic conditions. Adding steel fibers to SMA mixtures greatly enhances the deformation resistance of the mixture and its overall mechanical properties [1] [Fig. 4].

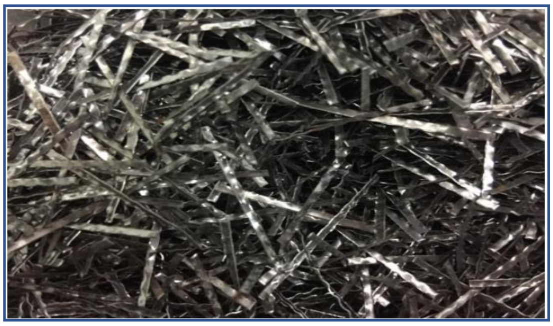


Fig. 4 Steel Fiber

3.4.3.5 Jute Fiber

Jute fiber is employed as a natural additive in Stone Matrix Asphalt (SMA) to improve its performance. It serves as a material stabilizer, stopping material separation in hot weather. The addition of jute fiber makes the SMA mix stronger and less deformable. The ideal content of jute fiber is approximately 0.3%, and this improves the performance of the mix by lowering drain down and enhancing stability. The application of jute fiber not only improves the asphalt but also offers an environmentally friendly option by utilizing a renewable resource [7] [Fig. 5].

Fig. 5 Jute Fiber

3.4.3.6 Cellulose Fiber

In Stone Matrix Asphalt, cellulose fiber improves the strength and durability of the pavement. It contributes to the formation of an integrated structure through its interfacial adhesion with the aggregates, preventing the asphalt binder from detaching, thus increasing skid resistance and reducing cracking. Wear and tear resistance of the mixture also gets increased through fibers, making roads safer and longer lasting. Cellulose fibers help SMA to efficiently control heavy loads of traffic along with maintaining high performance levels in every condition [8] [Fig. 6].

Fig. 6 Cellulose Fiber

3.4.3.7 Glass Macro Fiber

Cellulose fiber improves strength and durability of pavement in Stone Matrix Asphalt. Through its interfacial adhesion with the aggregates, it forms an integrated structure and prevents asphalt binder detaching from this matrix. The resistance to skid resistance as well as cracking is enhanced by it. Due to fibers, wear and tear resistance of the mixture gets increased that makes roads safer and longer lasting. Cellulose fibers help SMA to efficiently handle heavy loads of traffic along with maintaining high levels of performance under all conditions [8] [Fig. 7].

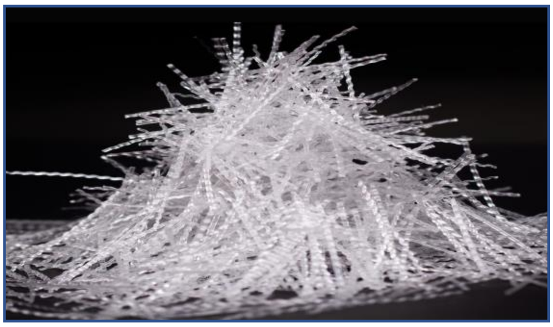


Fig. 7 Glass Macro Fiber

3.4.3.8 Waste Palm Oil Fiber

Waste palm oil fiber is a by-product from the palm oil industry, which can be added to improve stone matrix asphalt. Addition of WPOF in SMA increases the durability and strength of the asphalt mixture, thereby reducing the chances of damage. This also contributes to recycling waste while simultaneously reducing the cost of road construction. Different mixing methods will affect the performance of the WPOF-reinforced SMA, and it will have a better mechanical property and moisture resistance in the final product [10] [Fig. 8].

Fig. 8 Waste Palm Oil Fiber

3.4.3.9 Rice Straw Fiber

Rice straw fiber can be added to stone matrix asphalt to increase its strength and durability. At high temperatures, stability in the asphalt increases while at low temperatures, the cracking decreases. Adding rice straw into an asphalt mixture also enhances its moisture resistance and strengthens the overall material, enabling it to be an efficient material in road construction. Use of rice straw also avoids agricultural waste; an environmentally friendly and sustainable approach with the construction industry [0] [Fig. 9].

Fig. 9 Rice Straw Fiber

4. Properties

4.1 Marshall Stability Test

The Marshall Stability Test is crucial in determining the performance of stone matrix asphalt (SMA) mixtures, especially with fiber additives. This test measures the maximum load that a compacted asphalt specimen can withstand, showing its stability under traffic conditions. Different types of fibers, such as coconut, sisal, and steel, increase stability values; for instance, steel fibers enhance load-bearing capacity greatly, while natural fibers improve flexibility and moisture resistance. This also assesses the flow values of the mixture, that is, workability of the mixture. Overall, SMA mixtures with modified fibers generally achieve significantly improved mechanical properties and more robust durability in any given environment.

4.2 Indirect Tensile Strength

The indirect tensile strength test determines the tensile strength of SMA mixtures, which is an important indicator of their cracking resistance. Performance impacts of different fibers are as follows:

Coconut Fiber: Natural elasticity has the ability to enhance tensile strength by enhancing flexibility in the mixture, thereby less cracking under tension.

Sisal Fiber: It increases tensile strength quite effectively, gives better load distribution, and increases durability against fatigue.

Steel Fibers: Provides stronger reinforcement, dramatically increasing tensile strength and gives SMA a stronger resistance to deformation and cracking from heavy loads.

Each fiber type makes a unique contribution to the overall mechanical performance of SMA mixtures.

4.3 Rutting Resistance

This test determines the permanent deformation resistance of SMA mixtures subjected to traffic load. Different types of fibers indicate their specific effect on rutting resistance:

Coconut Fiber: This provides a higher degree of flexibility and elasticity, which reduces rutting by allowing the mixture to absorb stresses without permanent deformation.

Sisal Fiber: It enhances the global stability and resistance to rutting. Its effective distribution of the load provides durability to the asphalt material even under repetitive loading.

Steel Fiber: Highly enhances rutting resistance, since it has high tensile strength that provides excellent reinforcement, and the SMA mixtures are highly resistant to deformation under heavy traffic conditions.

Each fiber type adds uniquely to the performance and lifespan of SMA under traffic stresses.

4.4 Moisture Susceptibility Test

The test explains susceptibility of stone matrix asphalt (SMA) mixtures to damage induced by moisture. Different types of fibers have different impacts on moisture resistance: Coconut Fiber enhances moisture resistance by its hydrophobic properties, reducing stripping between aggregates and asphalt; Sisal Fiber enhances adhesion and minimizes water damage, thus increasing pavement life; Steel Fiber highly reinforces the mixture with effective reduction of moisture-induced damage, thus enhancing durability in general. Each fiber type uniquely contributes to the performance of SMA, which makes it more resilient against environmental factors that may compromise its integrity.

5. CONCLUSION

With different types of fiber inclusions, it has shown great improvements in the performance characteristics with SMA. Coconut and sisal-based natural fibers improved tensile strength and moisture resistance for the better durability of the SMA mix. Synthetic fibers especially steel fibers possess a superior strength for reinforcement of mixtures enhancing their rutting resistance and stability under heavy load. Material recycling due to the recycles of waste fibers such as textile waste and palm oil waste enhances mechanical properties and helps in sustainable practices. In a nutshell, fiber modifications enhance the performance of SMA applications in various environmental conditions and it is therefore suitable for high performance pavements.

Table 2 : Demonstrate different Filler materials used by the researchers

Sl. No	Author Year	Types of Materials	Ratios	Marshall Stability Test	Drain down test	Indirect Tensile Strength Test	Tensile Strength Test	Remarks
1	Bradley J. Putman et al. 2004	Waste tire fibers, waste carpet fibers, cellulose fibers, polyester fibers	0.3% by weight (constant for all mixtures)	----	----	Dry Cellulose-873kpa Tire-838kpa Carpet -856kpa Polyester-865kpa wet cellulose821kpa	Cellulose- 94.1% Tire - 100.9% Carpet - 101.8% Polyester-99.8%	carpet fiber mix had the highest PTL (14.7%)
2	Ibrahim M et al. 2006	Coarse aggregate, asphalt cement, cellulose fibers	Control:5.3 % SMA: 6.9%	Control Mixtures: Stability after 35 min immersion: 6.5kN Stability after 24 h immersion: 5.8kN SMA Mixtures: Stability after 35 min immersion: 5.0kN Stability after 24 h immersion: 4.5Kn	----	----	----	The tests conducted in the study reveal significant insights into the performance of Stone Matrix Asphalt (SMA) versus control mixtures. SMA exhibited lower Marshall stability but demonstrated superior resilience and reduced loss percentages in stability and tensile
3	Shaopeng Wu et al. 2007	Steel slag, Basalt, Modified asphalt binder (PG76-22)	80% Steel Slag / 20% Basalt	Steel slag-10.8kn Basalt-11.5kn	----	----	----	Steel slag, a byproduct of steel production, effectively serves as an aggregate in stone mastic asphalt (SMA) mixtures. It enhances high-temperature resistance, reduces low-temperature cracking, and meets environmental sustainability goals by recycling waste materials in construction
4	V. S. Punith et al. 2012	Moist aggregates, hydrated lime (1% and 2%), WMA additives (Asphamin, Sasobit, Evotherm), various binders	1% and 2% hydrated lime by weight of aggregate	----		448kpa	85%	Lowest Dry ITS: Found in mixtures with Aggregate C, Sasobit additive, 2% lime content, and 15% crumb rubber (CR). Highest Dry ITS: Observed in virgin mixtures with PG 76-22 + fibers containing Aggregate B with 1% hydrated lime.

Table 2 (continue)

Sl. No	Author Year	Types of Materials	Ratios	Marshall Stability Test	Drain down test	Indirect Tensile Strength Test	Tensile Strength Test	Remarks
5	Mahabir Panda et al. 2013	VG 30 bitumen, Crumb Rubber Modified Binder CRMB 60, coarse aggregates, fine aggregates, coconut fiber	Binder: 4% to 7%, Fiber: 0%, 0.3%, 0.5%, 0.7%	Without coconut fibers-15kn With coconut fibers-18kn	Without Fiber-120g With fiber-30g	Mixes without fiber VG 30 Bit-601.44kpa CRMB 60-741.97kpa Mixes with fiber VG 30 Bit-759.68kpa CRMB 60-950.28kpa	Mixes without fiber VG 30 Bit-78.67% CRMB 60-83.47% Mixes with fiber VG 30 Bit-85.87% CRMB 60-92.29%	Binder Properties VG 30 Bitumen: Penetration at 25 °C: 68 (0.1 mm) Softening Point (R&B): 48.5 °C Viscosity at 160 °C: 200cp CRMB 60: Penetration at 25 °C: 49 (0.1 mm) Softening Point (R&B): 62 °C Viscosity at 160 °C: 275cp Aggregate Properties Coarse Aggregate Physical Properties: Aggregate Impact Value: 14% Aggregate Crushing Value: 12% Los Angeles Abrasion Value: 18% Flakiness Index: 17.2% Elongation Index: 12.4% Water Absorption: 0.09% Specific Gravity: 2.65
6	Aline Colares do Vale et al. 2014	Coconut fibers, cellulose fibers, granite, hydrated lime, AC 50/70 binder	70-80% coarse aggregates, 6-7% binder, 8-12% filler, 0.3-0.5% fiber	----	coconut fibers: reduced from 0.08% to 0.04% cellulose fibers-0.01% without fibers-1.06%	Coconut Fiber: 0.76MPa Cellulose Fiber:0.76MPa Without Fiber:0.56MPa	Coconut Fiber:91% Cellulose Fiber:71% Without Fiber:50%	The tests demonstrated that SMA mixtures with coconut fibers showed improved moisture resistance and resilient modulus, while cellulose fibers enhanced tensile strength and fatigue performance.
7	Ashish Talati et al. 2014	Optimum Bitumen Content (OBC), Aggregates, filler, additives	OBC: 6.2% (Marshall),6% (SGC)	----	----	----	Greater than 80%	SMA mixes demonstrated excellent stability, high moisture resistance, reduced rutting susceptibility, and improved fatigue life, making them suitable for high-performance pavement applications.

Table 2 (continue)

Sl. No	Author Year	Types of Materials	Ratios	Marshall Stability Test	Drain down test	Indirect Tensile Strength Test	Tensile Strength Test	Remarks
8	Mario Manosalva s-Paredes et al. 2016	PMB 45/80-65 (SBS modified), PMB 45/80-65 R (rubber modified), cellulose fiber (0.3% and 0.5%)	Binder content: 5.9%	----	----	0.3% cellulose fiber: Dry ITS: 1831.0kPa Wet ITS: 1629.0kPa 0.5% cellulose fiber: Dry ITS: 1699.8kPa Wet ITS: 1433.0kPa Wet ITS: 1433.0kPa without cellulose fiber: Dry ITS: 1478.8kPa	0.3% cellulose fiber: 95.5% 0.5% cellulose fiber: 95.8% without cellulose fiber: 96.9%	Binder Drainage (D) 0.3% cellulose fiber: 0.14% 0.5% cellulose fiber: 0.05% without cellulose fiber: 0.05% Wheel Tracking Slope (WTS) 0.3% cellulose fiber: 0.084 mm/10^3 cycles 0.5% cellulose fiber: 0.056 mm/10^3 cycles without cellulose fiber: 0.038 mm/10^3 cycles
9	Nyoman Suaryana 2016	Lawele Granular Asphalt (LGA 50/25), 60/70 Pen grade asphalt	23% asphalt content, 6.54% optimum asphalt content in SMA mix	----	----	----	----	Dynamic Modulus, Wheel Tracking, Flexural Fatigue Testing Asbuton prevents asphalt drain down, increases filler proportion, and improves dynamic stability; Similar fatigue resistance to cellulose-stabilized SMA; Stiffer at high temperatures (>4.4°C) but less brittle at low temperatures
10	Shenghua Wu et al. 2016	Stone Mastic Asphalt (SMA), Hot Mix Asphalt (HMA)	----	----	----	20°C-HMA Strength: 2,992.3kPa SMA Strength: 2,581.4kPa 10°C:HMA Strength: 4,465.0kPa SMA Strength: 4,397.5kPa	----	Studded Tire Wear Test Results HMA Mean Mass Loss: 2.7 g SMA Mean Mass Loss: 3.3 g Fracture Work Density (HMA): 148.9kPa Fracture Work Density (SMA): 220.6kPa
11	Yanping Sheng et al. 2017	Flocculent lignin fiber, Mineral fiber, Polyester fiber, Blended fiber,	0.1% 0.2%, 0.3% 0.4%, 0.5% 0.6%’ fiber content	Blended fiber: 14.2kN at (0.5%) Polyester fiber: 13.4kN at (0.4%). Mineral fiber: 12.8kN at (0.6%) Flocculent lignin fiber 12.5kN at (0.6%)	----	----	----	Bulk Specific Gravity Flocculent lignin fiber- 2.50(0.1%) Mineral fiber-2.52(0.1%) Polyester fiber-2.51(0.1%) Blended fiber-2.51(0.1%)

Table 2 (continue)

Sl. No	Author Year	Types of Materials	Ratios	Marshall Stability Test	Drain down test	Indirect Tensile Strength Test	Tensile Strength Test	Remarks
12	N.L.N. Kiran et al. 2019.	Coir, Sisal, Banana Fibers, Bitumen, Aggregates, Filler, Additives	0.3% by weight of mixture for all fibers	----	----	Nil- 0.4253 Coir fiber- 1.1048 (0.3%) Sisal fiber- 1.0766 (0.3%) Banana fiber- 1.0762 (0.3%)	Nil- 52.23 Coir fiber- 98.270.3%) Sisal fiber- 97.37(0.3%) Banana fiber- 97.68(0.3%)	----
13	N E Jasni et al. 2020	60/70 penetration-grade asphalt, Cellulose fibers and glass macro-fibers crushed granite aggregates,	0%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6% by weight	18000kg at (0%) 22000kg at (0.2%) 20000kg at (0.3%) 21000kg at (0.4%) 18000kg at (0.5%) 18000kg at (0.6%) by weight	----	----	----	Cantabro Loss: The addition of 0.4% of steel fiber reduced Los Angeles Abrasion loss after 300 turns. Resilient Modulus: Mixture with 0.5% fiber content exhibited higher stiffness modulus compared to other mixes at 25°C while 0.4% for 40°C. Dynamic creep: For dynamic creep at both temperatures (25°C and 40°C). of at 0.4% with strain value of 1023.8 and 5440.4, respectively. Mixture with 0.5% fiber content exhibited higher permanent strain value compared to other mixes at 25°C while 0.4% for 40°C.

Table 2 (continue)

Sl. No	Author Year	Types of Materials	Ratios	Marshall Stability Test	Drain down test	Indirect Tensile Strength Test	Tensile Strength Test	Remarks
14	Alireza Ameli et al. 2020	Cowl waste ash(CWA), Rice husk ash(RHA), Limestone Powder	0:100, 25:75, 50:50, 75:25, 100:0	Fiber: c-5.5kN 100%RHA-7.5kN 25%CWA-5.6kN SBS: c-5.9kN 100%RHA-7.8kN 25%CWA-6.1KN		Fiber: DRY c-650kpa 100%RHA-770kpa 100%CWA-550kpa Wet c-550kpa 100%RHA-700kpa 100%CWA-530kpa SBS: c-790kpa 100%RHA-900kpa 100%CWA-610kpa Wet c-750kpa 100%RHA-810kpa	Fiber: c-0.82% 100%RHA-0.92% 100%CWA-0.948% SBS: c-0.963% 100%RHA-0.91% 100%CWA-0.972%	Dynamic creep test: A mixture containing 100% RHA and cellulose fiber and a sample containing 100% RHA and SBS increase the flow number by 32% and 49%. wheel tracking test Multiple stress creep recovery(MSCR) Linear amplitude strain (LAS)
15	Chandy Chin et al. 2021	Stone mastic asphalt, coconut fiber (5-20mm, 20-40mm, 40-60mm) AC 60/70 asphalt	0, 0.1, 0.3, 0.5, 0.7% coconut fiber aggregate	0.3%-7.14kn	0.25%	0.3%-2.5Mpa	----	----

Table 2 (continue)

Sl. No	Author Year	Types of Materials	Ratios	Marshall Stability Test	Drain down test	Indirect Tensile Strength Test	Tensile Strength Test	Remarks
16	Nura Shehu Aliyu Yaro et al. 2021	Waste Palm Oil Fiber, bitumen, Aggregate, waste granite dust	0%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6% by weight	Traditional mixing:11KN Sequential mixing:11.5KN (at 0.3% fiber dosage both values are concerned)	Traditional mixing:0.04% Sequential mixing:0.02% (at 0.6% fiber dosage both values are concerned)	DRY Traditional mixing: 860kpa Sequential mixing: 930kpa WET Traditional mixing: 780kpa Sequential mixing: 830kpa (at 0.3% fiber dosage both values are concerned)	Traditional mixing:93% Sequential mixing:94% (at 0.3% fiber dosage both values are concerned)	Cantabro Loss: Traditional mixing:4.1% Sequential mixing:4% (at 0.6% fiber dosage both values are concerned)
17	Sandeep Singh et al. 2022	Sisal, Coir, Rice Straw Fibers; Waste Marble as filler	0% 0.25% 0.3% 0.35% 0.4%	Sisal fiber 0.25%-7.533 0.3%-7.164 0.35%-7.900 0.4%-8.766 Coir fiber 0.25%-10.46 0.3%-10.610 0.35%-8.96 0.4%-10.033 Rice straw Fiber 0.25%-7.883 0.3%-10.700 0.35%-7.833 0.4%-9.633	For 0.3% Fiber Addition: Sisal: Reduction of drain down value by 65% Coir: Reduction of drain down value by 90% Rice Straw: Reduction of drain down value by 52%	Sisal fiber 0%-0.887 0.25%-0.9253 0.3%-1.13 0.35%-1.059 0.4%-0.986 Coir 0%-0.887 0.25%-1.069 0.3%-1.207 0.35%-1.046 0.4%-0.981 Rice Straw Fiber 0%-0.887 0.25%-1.075 0.3%-1.2284 0.35%-1.339 0.4%-1.12	Sisal fiber 0%- 87.79 0.25%-91.168 0.3%- 94.02 0.35%-91.579 0.4%- 90.691 Coir fiber 0%-87.79 0.25%-90.374 0.3%-93.45 0.35%-91.211 0.4%-90.241 Rice straw fiber 0%-87.79 0.25%-90.903 0.3%-91.73 0.35%-93.01 0.4%- 89.556	The tests demonstrate that optimal fiber content enhances the mechanical properties of SMA mixtures, improving tensile strength and moisture resistance, thereby ensuring better performance and durability in road applications.

Table 2 (continue)

Sl. No	Author Year	Types of Materials	Ratios	Marshall Stability Test	Drain down test	Indirect Tensile Strength Test	Tensile Strength Test	Remarks
18	F. Morea et al. 2023	Polymer modified binder, high viscosity crumb rubber, glass macro fibers, aggregates, lime	----	----	----	All mixtures complied with specifications (ITSR > 80%). The SMA CR showed an ITSR higher than 100, indicating no moisture damage	----	Multiple Stress Creep Recovery (MSCR) Test:Results indicated poor performance at these high temperatures, with high compliance values (Jnr) and low recovery (R) at 3.2kPa
19	Gonzalo Valdés-Vidal 2023	WTTF, rapid-setting cationic asphalt emulsion, water	----	----	----	----	----	Resistance to Cracking: The SMA mixes with 100% WTTF-based additive showed comparable resistance to cracking compared to traditional cellulose-based additives. Stiffness Modulus: The stiffness modulus of the SMA mixes was enhanced with the incorporation of the WTTF-based additive, indicating improved load-bearing capacity.

Table 2

Sl. No	Author Year	Types of Materials	Ratios	Marshall Stability Test	Drain down test	Indirect Tensile Strength Test	Tensile Strength Test	Remarks
20	Jiaqing Wang et al. 2023	Bamboo fibers, corn straw fibers, asphalt, aggregates	0.3% fiber	SMA with Bamboo Fiber-12kN SMA with Corn Straw Fiber-11.5KN	SMA with Bamboo Fiber-1.5mm SMA with Corn Straw Fiber-1.8mm	SMA with Bamboo Fiber -2Mpa SMA with Corn Straw Fiber-1.8Mpa	SMA with Bamboo Fiber-2.5Mpa SMA with Corn Straw Fiber-2.2Mpa	Fiber oil absorption test: Oil Absorption Multiplier: The surface treatment significantly reduced the oil absorption multiplier of the biomass fibers by approximately 0.6. Mass Loss: The mass loss of the treated fibers during the test was reduced by about 2% compared to untreated fibers. Dynamic stability test: SMA with Bamboo Fiber-2,800 SMA with Corn Straw Fiber-2,600
21	W. Rodrígue z et al. 2024 3-25	100% Peruvian cotton textile fiber, Polymer-Modified Asphalt PG 76–22, crushed granite	0.20% textile fiber, 6% asphalt	Textile fiber-12.5KN Commercial fiber-10.5KN	Textile fiber-0.3% Commercial fiber-0.5%	Textile fiber-1.8MpaCommercial fiber-1.5Mpa	Textile fiber-95% Commercial fiber-82%	Rutting Resistance Textile Fiber Mixture: Exhibited a rutting resistance of 2.82 mm. Commercial Fiber Mixture: Exhibited a rutting resistance of 2.46 mm.

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R.Vinay Kumar, B.Neeraj Sai, B.Yashoda: Were responsible for conceptualization, curation of datasets, investigation, formal analysis, and the creating, validating, and visualizing and themselves writing the preliminary draft.

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