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# Assessment of Stone Mastic Asphalt Performance in Road Pavements: A Comprehensive Review

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**Keywords:**
Stone Mastic Asphalt
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**A B S T R A C T**

Pavement structures are fundamental to road infrastructure, where durability and performance directly influence service life and sustainability. Stone Mastic Asphalt (SMA) has emerged as a superior asphalt mixture due to its stone-on-stone aggregate skeleton, which enhances volumetric stability and resistance to permanent deformation. This study reviews the performance enhancement of SMA through the incorporation of sustainable fillers and recycled materials as alternatives to conventional fillers. Compared to traditional dense-graded asphalt, SMA demonstrates up to 30–40% greater rutting resistance under heavy traffic loading. The inclusion of fibres, typically at 0.3–0.5% by weight, increases mixture stability by 15–25% and reduces binder drain-down by approximately 50%, promoting uniformity during placement. The volumetric behaviour of SMA is governed by the balance between mastic content and air voids; increasing the mastic by 1–2% reduces voids and enhances durability. Polymer modification of the asphalt binder further improves cohesion and adhesion, resulting in superior moisture resistance (Tensile Strength Ratio, TSR > 80%). Moreover, the use of sustainable fillers contributes to improved rutting resistance and long-term structural performance. However, optimal outcomes depend on precise mix design, appropriate material selection, and high-quality construction practices.

# دراسة مرجعية لأداء العجينة الإسفلتية ذات الفجوات في رصف الطرق

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**الكلمات المفتاحية:**
العجينة الاسفلتية
المواد المستدامة
التشوه الدائم
المواد المالئة

**الملخص**

تعد هياكل الرصف عنصرًا أساسيًا في البنية التحتية للطرق، حيث تؤثر المتانة والأداء بشكل مباشر على عمر الخدمة والاستدامة. وقد برز الأسفلت الحجري المازج (Stone Mastic Asphalt - SMA) كخلطة إسفلتية متفوقة بفضل هيكله العظمي الحجري-الحجري الذي يعزز الاستقرار الحجمي والمقاومة للتشوهات الدائمة. تهدف هذه الدراسة إلى مراجعة تحسين أداء SMA من خلال دمج الحشوات المستدامة والمواد المعاد تدويرها، كبدائل للمواد المالئة التقليدية. بالمقارنة مع الأسفلت الكثيف التدرج التقليدي، يُظهر SMA مقاومة أعلى للتخدد بنسبة تصل إلى 30–40% تحت الأحمال المرورية الثقيلة. يسهم إدخال الألياف، عادة بنسبة 0.3–0.5% من الوزن، في زيادة استقرار الخلطة بنسبة 15–25%، كما يقلل من نزيف الرابط الأسفلتي بنسبة تقارب 50%، مما يعزز التجانس أثناء الرصف. يتحكم التوازن بين محتوى الماستيك والفراغات الهوائية في السلوك الحجمي للخلطة؛ حيث تؤدي زيادة الماستيك بنسبة 1–2% إلى تقليل الفراغات الهوائية وتحسين المتانة. كما أن تعديل الرابط الأسفلتي بالبوليمرات يعزز التماسك والالتصاق داخل الخلطة، مما يؤدي إلى مقاومة أعلى للرطوبة (نسبة الشد المتبقي TSR > 80% ). علاوة على ذلك، تسهم الحشوات المستدامة في تحسين مقاومة التخدد والأداء الهيكلي طويل الأمد. ومع ذلك، فإن تحقيق النتائج المثلى لا يزال يعتمد على تصميم دقيق للخلطة، واختيار مناسب للمواد، وممارسات إنشائية عالية الجودة..

## 1. Introduction

In recent years, the global highway pavement construction industry has advanced rapidly in response to the deterioration of asphalt pavements, which can be greatly influenced by several factors, such as traffic volumes, unpredictable weather patterns, and the characteristics of the roadbed soil. These factors may shorten the pavement's usable life by accelerating pavement deterioration and causing early distress. By improving the quality of asphalt mixtures with the natural resources and environmentally friendly components,

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it is vital to evaluate the sustainable concepts on highways to develop a new procedure that leads to improved SMA mixture performance, which was created in Germany as a long-lasting surfacing material [1-2]. It was designed to enhance stone-to-stone contact through the careful selection of appropriate gradations [3]. The asphalt effectively fills the voids within the coarse aggregate skeleton, resulting in a dense structural matrix. This robust skeleton, capable of supporting heavy loads, is achieved through direct aggregate contact and tight interlocking [4]. On the other hand, the mastic, which exhibits high bonding strength and enhances the overall mechanical properties of SMA, forms through the interaction between asphalt and mineral powder [5]. SMA can withstand permanent deformation under severe vehicle loads because of the adequate vertical and lateral restraint provided by the coarse aggregate skeleton and mastic [6]. Because of its remarkable temperature stability, superior skid resistance, durability, and resistance to rutting, SMA is widely used in the construction of asphalt roads [7]. The rapid expansion of road infrastructure is straining the supply of traditional fillers such as lime and high-quality mineral aggregates. Consequently, there is a growing need to explore alternative materials to conserve existing mineral resources. If it can be shown that waste materials can be used without compromising pavement performance, if they prove to be viable technically, economically, and environmentally while meeting regulatory standards, the highway industry could potentially incorporate a substantial volume of sustainable materials [8 Numerous studies have demonstrated that the properties of the mineral filler and filter size significantly influence how well asphalt paving mixtures function in terms of moisture susceptibility, fatigue cracking, and permanent deformation. Because of the strong temperature dependence of asphalt cement's viscoelastic characteristics, loads greater than the viscosity of asphalt binder at higher temperatures cause it to become viscous and exhibit plastic flow. Excessive asphalt binder and insufficient internal friction between aggregate particles lead to plastic flow [9]. This highlights the need to improve the properties and characteristics of the current asphalt material. The use of fillers is one established technique for improving binder. Fillers have historically been employed to increase the stiffness of the asphalt binder at high service temperatures, therefore improving the temperature susceptibility of asphalt. The mastic that is created when fillers and asphalt binders are mixed improves service qualities across a broad temperature range. This mastic can be thought of as the element that holds the aggregate together with glue and deforms when the pavement is subjected to stress during use [10]. An asphalt mixture's performance impacted by durability, caused a mixture's qualities to fluctuate dramatically over time. Conversely, under specific traffic loading conditions, ageing, temperature fluctuations, and water action can cause pavement strain [11]. This review addresses key challenges in practical road engineering and examines relevant research papers investigating sustainable pavement materials suitable for SMA mixes.

## 2. LITERATURE REVIEW

### 2.1 Description of Stone Mastic Asphalt

“A gap-graded bituminous mixture consists of a high proportion of coarse aggregate and filler, with relatively few sand-sized particles. When applied, it creates a surface with abundant macrotexture and low air voids, resulting in excellent drainage and waterproofing.”

High course aggregate concentration in SMA creates voids in the structural matrix, which are then filled with high viscosity mastic and any stabilising agent to form a stone-on-stone skeleton. Figure.1 provides a comparison of the structures of gap-grade, dense grade and open grade [12].

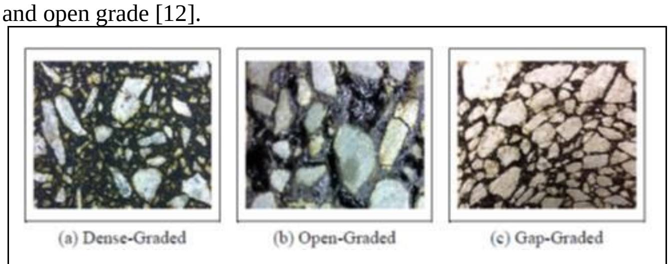


**Fig. 1.** Comparison of Common Asphalt Mix Types [12].

These key components of the SMA combination are shown in Figure. 2. [13].

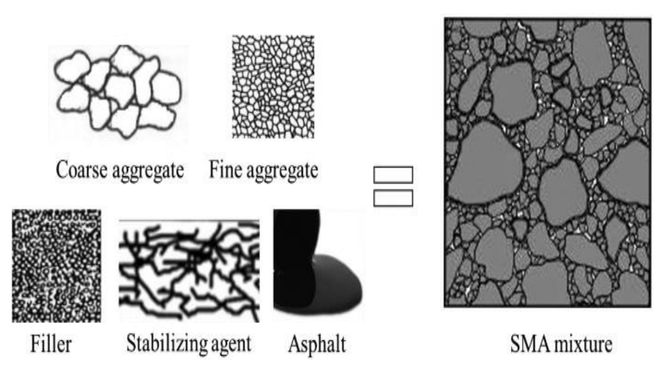


**Fig. 2.** Composition of SMA [13].

### 2.2 Advantages of Stone Mastic Asphalt (SMA)

**Durability:** SMA is a highly durable surface due to its stone-on-stone contact, which enhances resistance to rutting.

**Improved Skid Resistance:** The coarse aggregate structure of SMA, making it safer for vehicles, especially in wet conditions.

**Reduced Noise:** SMA surfaces tend to generate less noise compared to traditional asphalt.

**High Stability:** The stone skeleton structure of SMA offers high stability, making it suitable for high-traffic and heavy loads.

**Resistance to Aging:** The high binder content and use of fibres in SMA reduce oxidation, extending the pavement's lifespan.

**Reduced Maintenance:** Lower maintenance expenses are a result of SMA's resilience to deformation and longevity.

The main disadvantages are the higher material and production costs that are associated with higher mastic contents. So by weighing these, decision-makers can determine whether Stone Mastic Asphalt is suitable for specific paving projects based on traffic load, environmental conditions, and budget constraints. [14].

### 2.3 Materials of Stone Mastic Asphalt (SMA)

SMA is composed of a specific mixture of materials designed to create a durable, high-performance pavement. Table 1 showed the primary materials used in SMA. [15-16].

**TABLE 1.** The Primary Materials Used In SMA

| Material | Description | Purpose | Proportion |
|---|---|---|---|
| Coarse Aggregate | Crushed stone or gravel. | Provides the stone-on-stone contact necessary for structural stability. | 70-80% |
| Fine Aggregate | Crushed or natural sand. | Fills the voids between the coarse aggregates. | 10-20% |
| Mineral Filler | Limestone dust, cement, or hydrated lime. | Fills the smallest voids in the mixture, improving the asphalt's stiffness. | 8-12% |
| Asphalt Binder | Asphalt cement. | Acts as a binding that coats aggregates and holds the mixture together. | 5-7% |
| Fibbers | Cellulose or mineral fibers. | Prevents binder drainage during production and laying. | 0.3-0.5% |
| Additives | Polymers, anti-stripping agents, or chemicals. | Improves resistance to moisture damage. | - |

## 3. PERFORMANCE CHARACTERISTICS OF SMA

### 3.1 Asphalt Mixture Preparation

Numerous studies have shown that the characteristics of the mineral filler and sieve size have a major effect on how well asphalt paving mixtures operate, particularly in terms of permanent deformation, fatigue cracking, and moisture susceptibility. Mineral filler is an essential part of asphalt mixtures because of its vital function in stiffening and toughening the asphalt binder [17]. Given that the viscoelastic the characteristics of mastic are strongly temperature-dependent; at higher temperatures, loads greater than its viscosity cause asphalt binder to become viscous and exhibit plastic flow. This plastic flow occurs due to a lack of internal friction between aggregate particles and the use of excess asphalt binder. This has highlighted the need to enhance and improve the characteristics and properties of existing asphalt material [18]. Fillers have historically been employed to increase the asphalt binder's stiffness at high service temperatures, therefore improving the asphalt's temperature susceptibility. The mastic that is created when fillers and asphalt binders are mixed improves service qualities across a broad temperature range. This mastic can be thought of as the element that holds the aggregate together with glue and deforms when the pavement is subjected to stress during use [19].

Liu, S., et al. (2021) reported that one of the key aggregate properties that influences the long-term deformation of HMA is gradation. Technically, the gap-graded mix consists of discrete, single-sized aggregates that are glued together by binder-rich mastics. These principal components provide the gap-graded mix with a stone-on-stone structure, as demonstrated in Figure 3, this allows it to support two significant traffic loads and offer long-term endurance [20].

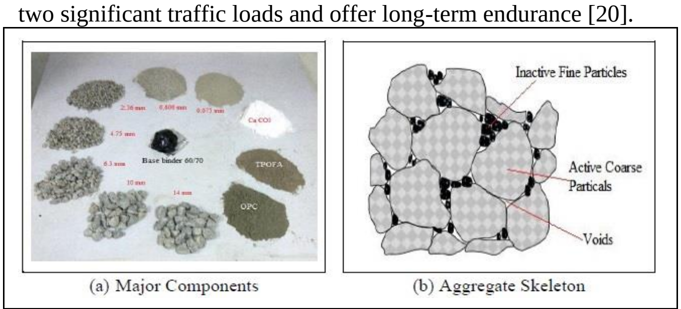


**Fig 3.** Components and Aggregate Skeleton of SMA

Jiasheng Zhu et al. (2023) [21] carried out extensive laboratory research to enhance the performance of SMA combinations and lower the enormous amount of face mask waste (MF). The results demonstrated that adding MF to the SMA Mix improved the material's resilience modulus, indirect tensile strength, resistance to permanent deformation, and binder drain-off performance.

Choudhary, J. et al. (2020) [22] stated that due to their varying features, different fillers can alter the binder's chemical or physical properties in different ways. This alteration process is significantly impacted by the following variables: three elements: the kind of filler, the amount of it in the combination, and its physico-chemical activity.

Banana and coconut fibre were investigated by Pragnya P. (2020) [23] as additives. The experiment's findings that 0.3% of fibre can satisfactorily boost Marshall Characteristics and the coconut fibre-stabilized SMA has a higher specific gravity than the banana fibre-stabilized SMA.

Rose Mary X. (2018) reported that coarse aggregate constitutes a significant portion of the material in stone mastic asphalt, with a thick coating of mastic and fiber binding the aggregates together. This formulation ensures better interlocking and excellent stone contact. The fibers improve aggregate-to-aggregate contact and enhance bonding. When fibers are introduced, binder drainage is greatly reduced. SMA can maximize resistance to rutting while also providing increased pavement durability and a longer service life [24].

Dang Van Thanh et al. (2013) studied the influence of abnormally high temperatures on the dynamic stability of SMA mixtures using Chinese-fibers as shown in Figure 4. The results indicated that the dynamic Stability of all three fiber types in SMA mixtures decreased as the temperature increased [25].


**Fig 4.** Three types of Chinese-grown fibers [25].

Recent research by Jing Li et al. (2023) used nanoparticles to improve the performance of asphalt concrete (AC) mixtures while mitigating the negative impacts of polymers. This strategy has generated a lot of interest. Pavement specialists have determined that the best approach to handle the problems with binder additives and fulfil asphalt mixture standards is to modify asphalt using composite materials [26].

Seyed Ali Sahaf et al. (2022) evaluated low-temperature cracking of Stone Mastic Asphalt (SMA) mixtures with reclaimed asphalt pavement (RAP). The findings demonstrated that mixtures with 30% RAP had a greater critical stress intensity factor than combinations without RAP. Consequently, the addition of RAP resulted in brittle fractures in the combination at low temperatures and had no effect on the mixture's ability to absorb energy. Only samples with minimal air voids and a high loading rate showed a significant effect of RAP on the crack path, which resulted in a more prominent crack path through coarse aggregates with smaller diameters and mastic than in samples without RAP [27].

According to Masoudi et al. (2017), warm mix asphalt made with steel slag had a higher short- and long-term tensile strength than hot mix asphalt including limestone, as seen in Figure 5. This is thought to be related to the modified binder's higher adhesive and cohesive bonding than the regular binder, as well as the utilisation of better adhesion that is, slag instead of limestone. Higher ITS values were associated with better resistance to asphalt mixture fracture and a decreased propensity for stripping [28].

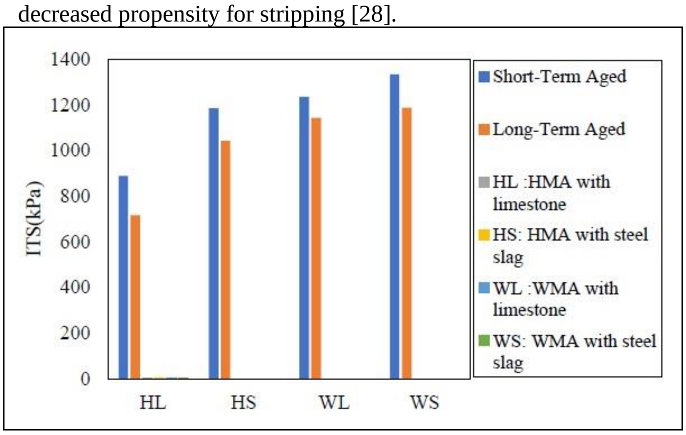


**Fig 5.** Indirect Tensile Strength Result [28].

SMA has a relatively open surface texture that reduces the air pumping mechanism and thus reduces noise [29].

Puccini, M., et al. (2019) assessed the benefits of employing crumb rubber in the creation of low-noise gap-graded asphalt concrete surfaces using both the wet (GGW) and dry (GGD) methods. The computed values presented in Table 2 show that the GGW mix's MR is higher than the GGD mix's. This increase is a result of higher temperatures in the field improving mixture compaction [30].

**TABLE 2.** Resilience Modulus at Representative Frequencies

| **Temperature (°C)** | **0** | | **10** | | **20** | |
|---|---|---|---|---|---|---|
| **Frequency (Hz)** | **1** | **10** | **1** | **10** | **1** | **10** |
| $M_R$ for GGD (MPA) | 9637 | 12594 | 5341 | 8202 | 2482 | 4434 |
| $M_R$ for GGW (MPa) | 14876 | 17944 | 9076 | 12483 | 5270 | 7212 |

According to Kringos and Scarpas (2008), Moisture damage is caused by "pumping action," which is the creation of strong water pressure fields inside the mixture as a result of traffic loads. Moreover, as Figure 6 illustrates, the combined impacts of mechanical and physical moisture damage decrease the aggregate-mastics link (molecular moisture diffusion) and mastics (erosion process) [31].

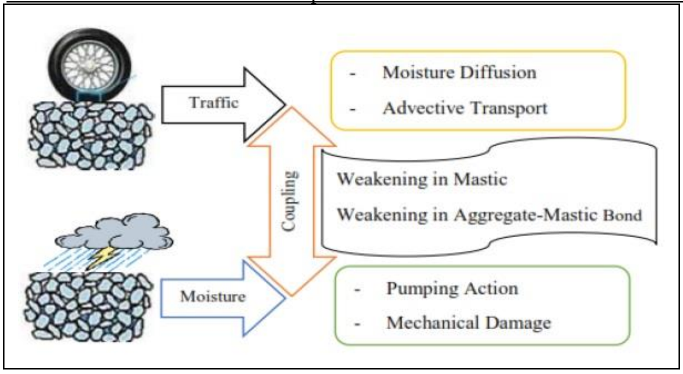


**Fig 6.** Schematic of the New Approach towards Moisture Damage [31].

The diagram indicates that the strong flow was caused by water passing through the gaps in the asphalt mixture. On the other side, water diffusion occurred when an underground leak caused water to infiltrate through the asphalt mastics.

According to Hamzah et al. (2015), the adhesion condition at the asphalt binder and aggregate interface may be described by adapting the chemical processes surface energy, molecule orientation, and mechanical adhesion theories. Furthermore, the water can influence the cohesion in several ways, including the weakening of mastics due to moisture saturation and void swelling or expansion. [32].

Hafeez et al. (2016), concluded that when aggregate size increases, the asphalt mixture's rut value drops. Furthermore, it was discovered that temperature significantly affected the SMA rut depth, particularly in combinations with small aggregate size. Table 3 presents this in a very obvious manner [33].

**TABLE 3.** Rut Depth in SMA Mixtures

| Nominal Maximum Aggregate Size (mm) | Rut Depth of Mixtures (mm) | | |
|---|---|---|---|
| | 25ºC | 40ºC | 60ºC |
| 25.4 | 2.14 | 4.67 | 6.6 |
| 19 | 2.50 | 6.95 | 9.03 |
| 12 | 2.71 | 9.97 | 12.17 |
| 9.5 | 3.13 | 12.7 | 15.14 |

Oluwasola et al. (2016) investigated utilizing steel slag from electric arc furnaces (EAF) and copper mine tailings (CMT) as substitute aggregate ingredients in asphalt mixtures. In comparison to the control mix, they discovered that the mixtures exhibited superior rutting performance and were less prone to persistent deformation. Furthermore, as Figure 7 illustrates, the results showed that the SMA were more resistant to rutting than the ACW 14 mixtures, with a reduced rutting rate [34].

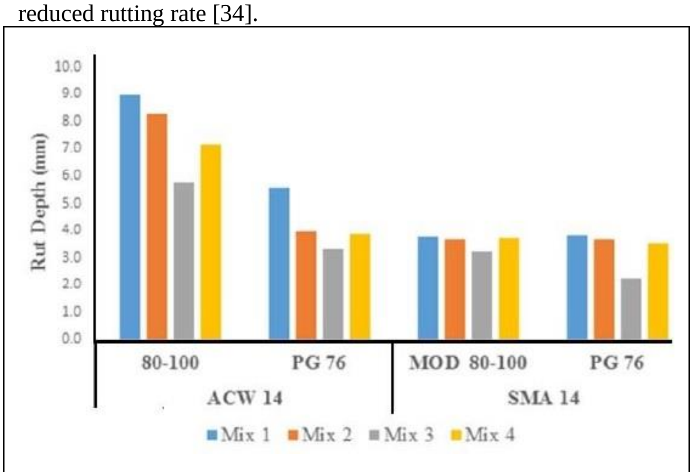


**Fig 5.** Rut Comparison between SMA and ACW 14 Mixtures [34].

Pavement design is crucial for determining the strength and performance of asphalt mixtures. Consequently, SMA has attracted considerable attention in road engineering research because of its excellent resistance to wear and plastic deformation [35,36].

## 4. Conclusion

The present study highlights the significance of material quality in pavement structures, compliance with standard specifications, and the potential of incorporating alternative and waste materials into SMA mixtures to enhance performance.

1. The stone-to-stone aggregate skeleton achieved through proper gradation design preserves volumetric stability. Research indicates that SMA exhibits up to 30–40% higher resistance to permanent deformation compared with dense-graded asphalt mixtures under heavy loading.
2. The addition of fibers (cellulose, synthetic, or waste fibers) improves stability by 15–25% in Marshall Stability tests and effectively reduces binder drain-down by up to 50%, ensuring mix uniformity during production and laying.
3. A clear relationship exists between air void content and mastic volume. Studies show that as mastic content increases by 1–2%, the air voids in SMA decrease proportionally, improving durability but requiring balance to prevent bleeding.
4. The performance of SMA mixtures is strongly influenced by mastic properties, with mixtures containing optimized mastic showing 20–30% better rutting resistance and 10–15% higher indirect tensile strength compared with control mixes.
5. The incorporation of polymers into asphalt binders significantly enhances performance. Polymer-modified SMA demonstrates 25–35% improvement in moisture resistance (TSR values >80%), and increases cohesion/adhesion of mastic, resulting in longer service life in wet and hot climates.

In summary, SMA provides notable performance benefits, particularly in terms of rutting resistance (up to 40% improvement), skid resistance (by 15–20%), and overall durability compared with conventional dense-graded mixtures. However, successful implementation requires rigorous mix design, appropriate material selection, and strict construction practices. Long-term field monitoring remains essential to validate these laboratory findings. Future research should focus on the optimization of local waste-derived fillers and fibers, where modifying filler content by 5–10% or fiber dosage by 0.3–0.5% by weight of mix may yield further performance gains while promoting sustainability. Future research should focus on long-term field validation and on the optimization of local waste-derived fillers and fibers to further enhance the sustainability and performance of SMA.

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