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COMPARISON OF STABILITY AND VOLUMETRIC PROPERTIES OF CONVENTIONAL AND STONE MASTIC ASPHALT

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Abstract: This study experimented with and compared the performance stability, volumetric properties, and resistance to rutting of SMA and CMA under simulated traffic loads. It was found in the Marshall Stability Test that SMA can withstand much higher stability (15.8 kN) than CMA (10.6 kN), thus demonstrating that we are far more resistant to any plastic deformation. In addition, SMA demonstrated better flow values (3.2 mm vs. 2.7 mm) and density (2.34 g/cm³ vs. 2.28 g/cm³) indicating suitability for high-stress pavements. Volumetric analysis demonstrated that SMA has higher Voids in Mineral Aggregate (VMA: 17. These are better than CMA (VMA 15.2%, VFA 75%) in binder to aggregate ratio and stability (5%) and Voids Filled with Asphalt (VFA: 80%) compared to CMA (VMA: 15.2%, VFA: 75%). Additionally, SMA's lower air void content (VTM: 3%). Less water ingress and slower aging concerning CMA's 4.0% (vs. 0%) By minimizing binder loss and improving durability, the binder drainage rate of SMA (0.2%) was much lower than that of CMA (0.8%). It found that rutting resistance was higher for SMA (25.3 mm; 50,000 load cycles; 12.0% strain at failure) than CMA (30.6 mm; 50,000 load cycles; 14.2% strain at failure), demonstrating its long-term deformation resistance under heavy traffic. In addition, SMA proved to be stiffer (1500 N/mm vs. CMA’s 1200 N/mm) and better suited for high-traffic roads. SMA finally has superior performance, durability, and rutting resistance and therefore represents an excellent choice for heavily trafficked roads despite a somewhat higher initial cost than HMA, and because the life cycle cost of SMA pavement is lower than for HMA. This enhances properties to reduce maintenance and service life, resulting in cost-effective solutions for high-stress pavement applications. SMA's sustainability and affordability could be further improved if more research is undertaken into recycled materials and their environmental impacts.
Keywords: Stone mastic asphalt; Conventional mix asphalt; Pavement durability; Stability properties; Binder content; Marshall stability test

1 INTRODUCTION

Increasing expectations of exceptionally flexible and durable asphalt under emerging activity conditions led to the development of modern black-top mixes like SMA [1]. SMA was developed in Germany during the 1960s, to negotiate with the rutting resulting from studded tires on streets [2]. SMA’s particular plan with a high rate of coarse aggregates (generally 70-80%) creates stone on a stone structure which provides better mound distribution and rigidity compared to conventional mix asphalt (CMA) that contains 40-60% coarse aggregates and relies on network support [3, 4]. Relative to CMA, SMA’s interlocking structure offers a significantly superior bearing capacity and greater mechanical resistance to rutting within high-traffic zones, which is essential when lengthening the durability of asphalt pavements and reducing maintenance expenses [5, 6]. These structural areas of interest extend well beyond stack dispersion at SMA. By introducing stabilizing added substance of cellulose fibers also synthetic polymers folio seepage is reduced which increases solidness and durability under harsh conditions in this way the performance of structure is enhanced [7, 8]. Investigations have shown that these enhancements enhance a strong SMA mechanical property and increase environmental sustainability since materials that can be recycled may be incorporated as reinforcements [9, 10]. Such characteristics make SMA a more appropriate solution for critical-stress applications and adverse natural environments, high temperatures, and excessive car loads inclusively [11]. SMA’s global utilization has transmuted drastically since its inception in Germany particularly in regions with intensive traffic and the need for extremely robust asphalts [12, 13]. Observations that SMA has a coarser total structure, and additional stable substances such as cellulose filaments, seem to minimize rutting compared to densified black-top blends [14, 15]. This has made SMA especially flexible in places where severe climate prevails due to enhanced asphalt stiffness which enables maintenance cost reduction [11, 16]. The major differences between SMA and CMA include; Solidness & Trench resistance. Agreeing to ask, the stone construction, as evident in SMA’s interconnectivity, can also handle monotonous loads and resist distortion as indicated in highly stressed situations, resulting in longer benefits. Subsequent tests on the contrast between SMA’s execution and that of CMA have repeatedly underscored this attribute – SMA rutting and greater load-carrying capacity under high-traffic situations [17, 18]. Another essential aspect by which SMA is differentiated from CMA is its extended cover substance that increases its integration of resistance and strength to organic injury [19, 20]. Regarding the considering acceptances, the higher cover substance in SMA maintains and reduces temperature-sensitive fracture, which is a major concern in areas with fluctuating temperatures and normally bonded with strands or polymers [21, 22]. This more

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noteworthy folio concentration forestalls SMA to keep flexibility and to thwart it from breaking, increasing its durability when confronted with temperature differences. To stay away from cover waste, which may be an issue because of the high cover fixation, strands, and other stabilizing included added compounds tend to be blended with SMA [20, 23]. The utilization of added substances like cellulose, and engineered or reused filaments molds a organize inside the folio, which enhances SMA's usually robust and powerful performance [24, 25]. Later ponder highlights the twin benefits of these added substances: While at the same time enhancing SMA effectiveness and equally reducing the natural effect that accompanies the use of recycled materials [26, 27]. When considering the reliability of comparing SMA and CMA it seems that SMA performs better than CMA. While CMA is commonly used due to its moo fetched, it requires the long-term strength needed for high-stress conditions based on the lattice structure rather than the stone-to-stone structure found in SMA [28, 29]. This important qualification makes SMA a more robust solution, specifically in ranges where very high activity and severe conditions are expected [30, 31]. Even though SMA's underlying costs can be Northwestern of CMA, its diminished tendency to require backing and have a longer benefit life makes it a more profitable choice over the long haul [32, 33]. Stone matric asphalt and conventional hot mix asphalt can be seen in Figure 1.

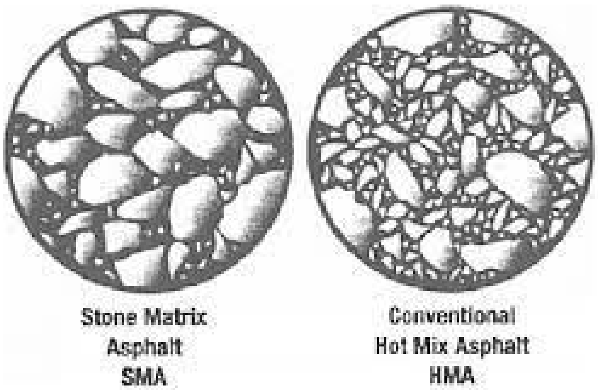

Figure 1 Stone Matric Asphalt and Conventional Hot Mix Asphalt

2 MATERIALS

2.1 Aggregates

Coarse aggregates are the most elemental constituent in both SMA and CMA mixtures. SMA employs a high degree of coarse aggregates (70-80%) to provide a stone-on-stone contact to improve load-bearing capacity and anti-trenching substantially. Instead, CMA generally has a small number of coarse totals (40-60%), and the cohesive network must bear the structure.

2.1.1 Coarse aggregate

In table 1, the coarse aggregates that are needed in SMA mixes are normally sourced from Bajawar an area that is famous for quality and durable shake mixtures. These totals are overwhelmingly of stone which is preferred for its hardness, durability, mainly its capability of withstanding harsh weather conditions and toughness. Granite's structure excites stone-on-stone relationships, which is important for the stability and load resistance of SMA blends. The sort of rock of the chemical cosmetics of the grain common fallbacks has been identified to be wealthy in minerals such as quartz, feldspar, and mica therefore shaping the impacts of the aggregates. Most important, quartz, this ingredient, boasts an incredible hardness while feldspar does shift basic judgment under vast weights. Presently, the elongation of mica increments flexibility and flexibility as they enable the SMA combination to cope far better with stretch and misshaping. This particular mineral shows that SMA asphalts possess remarkable toughness, minimal rutting tendency, and unique resistance to cracking known as weakness splitting.

Thus using stone aggregates from locations such as Bajawar in SMA combinations not only provides longevity but also facilitates the mechanical interlocking of particles to enhance the stability and performance of the mixture with time:

Table 1 Chemical Composition of Coarse Aggregate

Chemical Component	Composition(%)
Silica (SiO_2)	67.5
Alumina (Al_2O_3)	11.1
Iron Oxide (Fe_2O_3)	4.25
Calcium Oxide (CaO)	5.15
Magnesium Oxide (MgO)	3.12
Potassium Oxide (K_2O)	6.5
Sodium Oxide (Na_2O)	2.25

2.1.2 Fine aggregate

In table 2, coarse totals like coarse aggregates, sands, gravels, etc., are often purchased from the same quarry or the same area to ensure fabric continuity and establish regularity in black-top mixes. Fine totals from the same location generally have a reasonable mineral composition, which results in much better holding and enhanced steadiness of the ultimate combination. This article about minerals focuses on similarities that make quality control easier and advance fabric execution; silica concentration, hardness, and molecule shape. Thus if there is equality of root mean of fine and coarse aggregates, certain characteristics align superior interior of the stone mastic asphalt SMA network. This positioning carries forward the densification of the mix both in terms of mass and strength by guaranteeing that SMA is underpinned by a strong structure where stone-on-stone contact is maintained by small particles that uniformly fill the gaps:

Table 2 Chemical Composition of Fine Aggregate

Chemical Component	Composition (%)
Silica (SiO_2)	72.3
Alumina (Al_2O_3)	8.5
Calcium Oxide (CaO)	6.8
Magnesium Oxide (MgO)	2.1
Iron Oxide (Fe_2O_3)	2.3

2.2 Bitumen

In table 3, bitumen acts as a crucial portfolio in Stone Mastic Asphalt (SMA) holding the overall particles together and bringing elemental cohesiveness as well as quality. SMA contains a larger stone aggregator content of the order of 6.5 percent or more as compared to the CAM which typically contains 5-6 percent. This higher cover substance goes a long way in SMA's enhanced resilience, reducing its likelihood of deformation under compact loads and enhancing the pavement's useful life. In SMA a 60/70 entrance review bitumen is frequently used to maintain the cover at high temperatures, reducing the chances of mater foil flow or ''dying'' in warmer climates. This review of bitumen provides the required balance of flexibility and rigidity in black-top blends that compete in a range of natural conditions. Its height in carbon and hydrogen makes bitumen appropriate for its cement and flexibility which enables it to bind totals and adjust to relaxed tension without cracking. Sulfur and oxygen also help in their performance, improving the adhesion to totals and improving the strength at varying environmental conditions. That is why bitumen performs exceptionally well in SMA combinations, where high attachment and rigidity are critical to the long-term stability of the asphalt.

Table 3 Chemical Composition of Bitumen, Peshawar

Chemical Component	Composition (%)
Carbon (C)	85.7
Hydrogen (H)	9.5
Sulfur (S)	3.2
Nitrogen (N)	0.4
Oxygen (O)	1.2

2.3 Stabilizing Additives

Binder materials include cellulose and manufactured strands that are used to SMA so as not to allow the cover to seepage thus affecting the mixture's performance and durability. These filaments accumulate on the cover and form a network that maintains the cover in position, reducing loss during mixing and compaction. SMA often uses cellulose, polyester, and ordinary fiber like coconut or bagasse. These filaments help build a thicker folio film over the total particles of the mix and increase the stability besides reducing the possibility of free spillage of the cover beneath the heavy loads.

To make reliable and easily available choices in our application, cellulose fibers were selected as conventionally used fibers characterized by a high cellulose content. These fibers effectively encase a stable organization within the page, reducing page movability and increasing the stability of the SMA blend. This strategy gives a long-term, strong, and stable asphalt that does not distort, indeed even under strong activity and dynamically changing weather conditions.

2.4 Filler

In table 4, other aggregates like limestone clean or other mineral powders are essential in SMA since they advance the bond between the folio and the totals and reduce the gap holes. These fillers help improve the consistency of the mastic (bitumen-filler composition) since they preclude openings and enhance the overall structure, enhancing the durability of the performance of the blend. Thus in our case, limestone tidy was preferred for its high calcium carbonate content which enhances the bond strength between folio and totals and also increases the strength of the SMA mixture. In addition, the crucial content of magnesium carbonate improves the workability of the limestone tidy increases the strength of the mix, while the minor contents of silica and press oxide are useful to give basic keenness and wear resistance. The use of limestone cleanses as a filler further progresses moving between the folio and totals and thereby occurring in a relatively more stable and sustainable blend of black-top. Coarse aggregate, fine aggregate, limestone dust can be seen in Figure 2.

Table 4 Chemical Composition of Lime Stone Dust, Peshawar

Chemical Component	Composition (%)
Calcium Carbonate ($CaCO_3$)	93.4
Magnesium Carbonate ($MgCO_3$)	2.5
Silica (SiO_2)	1.8
Iron Oxide (Fe_2O_3)	0.7

Figure 2 Coarse Aggregate, Fine Aggregate, Limestone dust

3 METHODOLOGY

3.1 Introduction

The procedure for this thing is intended to eradicate any remoteness and deep contrast in the execution of Stone Mastic Asphalt (SMA) and Conventional Asphalt Mix (CMA). The process links research facility testing with the help of certain guidelines approved by ASTM D6927-15 to ensure precision and uniformity. The ponder is separated into four major stages: Consider plan, fabric characterization, testing techniques, and information analysis. Every one of these stages is deliberately constructed regarding the amassing of definitive information focal points and experiences, permitting, finally, a total correlation of SMA and CMA and their respect soundness, volumetric characteristics, and folio supervision. Flow chart of work can be seen in Figure 3.

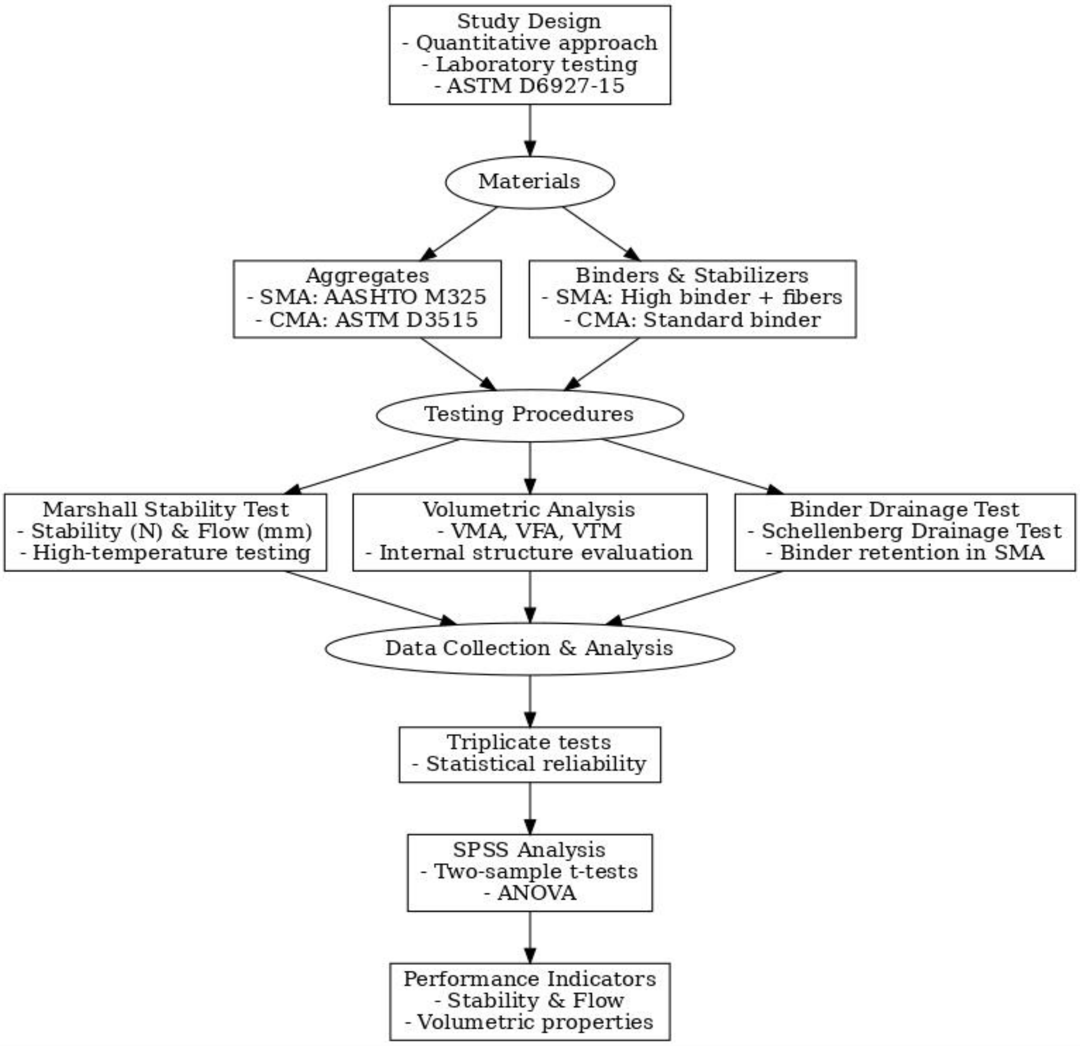

Figure 3 Flow Chart of Work

3.2 Study Design

This consideration adopts a quantitative analysis whereby SMA's steadiness and volumetric episodes are compared to those of CMA. The selection of the fundamental method of research facility testing was to minimize bias by providing controlled environments and accurate and precise data acquisition, thus providing a proper idea of the mechanical and strength characteristics of each material. The exploratory plan was dependent on the ASTM D6927-15, which provides a standard practice to assess the quality of black-top blend using Marshall Solidness Testing [34, 35]. In addition, the consideration was stimulated by earlier findings on the sufficiency of SMA under high-load conditions given its enhanced folio content and total highlights common to enduring distortion. [36].

3.3 Materials

Such materials involved in this study encompass aggregates, binders, and stabilizing fibers appropriate to each asphalt mixture.

Aggregates: Both SMA and CMA tests were carried out using locally available totals meeting ASTM and AASHTO requirements. The SMA total degree acquired after AASHTO M325, with a coarse-aggregate skeleton that advances stack dispersion and turns essential firmness[37]. CMA totals were selected to satisfy ASTM D3515 which is an all-around used blend and lies in the range of routine asphalts. Conduct of degree investigation was carried out to ensure conformity since variations in total degree can significantly affect volumetric attributes, stability, and by and large blend strength [38].

Binders and Stabilizers: SMA was produced using a tall cover material which consisted of polymer-modified black-top and stabilizing fiber. These fibers, typically cellulose or mineral in nature, reduce cover wastage during compaction while too far travel forward enhances blend strength and rigidity [39, 40]. The folio does explicit work in SMA as it contributes to gaps in the layperson's general information and results in increased vulnerability resilience. CMA tests, on the other hand, were compared with ordinary cover material and no extra stabilizers to refer to standard mix proportions often employed in interstate construction. [41].

3.4 Testing Procedures

To comprehensively evaluate SMA and CMA properties, the following testing protocols were applied:

Marshall Stability and Stream Test, which is among the central tests on the black-top blend plan, was used to assess load-carrying capacity (stability) and distortion under load (flow) [42, 43]. Both tests were conducted under a 60°C water shower for 30 minutes sometime before testing by ASTM D6927 to simulate high-temperature performance on the road. Reduced bulking values have been expressed in Newton's (N) to exhibit the strength of each mix for preventing plastic deformation while the streaming values were expressed in millimeters (mm) to show the flexibility of the fabric. Previous considerations on past errands SMA more regularly demonstrates moved forward strong solidities due to its interlocking total structures and lesser advice substance. This hypothesis was attempted in this examination [44]. Marshall stability test machine, samples can be seen in Figure 4.

Figure 4 Marshall Stability Test Machine, Samples

Volumetric characteristics were done to superior get it each mix's foundational format and the potential effect on future performance. The key parameters were:

Voids in mineral aggregates (VMA): A mathematical formula has been proposed to determine the amount of discus void space required inside the total to accommodate the black top cover. Thus, those markets displaying higher levels of VMA call for much better plausibility regarding cover preservation, which is crucial for SMA success [34].

Voids Filled with Asphalt (VFA): The frequency of VMA filled with black-top cover; more high VFA values are expected for SMA owing to its high folio content that increases strength and resistance to tearing [45].

Voids in whole Mix (VTM): VTM stands for the voids inside the fully compacted blend. They are expected to be less in SMA, which leads to improved rigidity and resistance to lasting distortion. Improving VTM is critical as it determines two major factors affecting the lifetime of asphalt, namely water permeability and freeze-thaw stability [46].

Binder Drainage Test: The Schulenburg Seepage Test was employed in assessing folio waste in SMA. They might be applied to determine the likelihood of folio runoff in open-graded mixtures. The high temperatures were linked with the blend to replicate transit and consolidation processes. In general, the balance in folio maintenance also reveals an optimal relation between folio substance and stabilizer viability to ensure that folio misfortune is minimized and blend soundness is maintained [47].

3.5 Data Collection and Analysis

To maintain factual uncompromising consistency, data was collected for each control group as three replicas per trial. Several tests were carried out on both SMA and CMA: Marshall Solidness and stream, VMA VFA, and VTM. To boost preciseness, the assignable examination was conducted by the SPSS computer program. The significance of various contrasts between SMA and CMA discoveries was evaluated with a two-sample t-test and ANOVA.

Stability Comparison: Soundness and stream execution estimations were used to examine the burden-bearing strength of SMA and CMA under recreated movement conditions. Because of the coarse total structure and fiber-stabilized cover of SMA, it was expected that SMA would have more express steepness values, as per earlier research on SMA blends under high-pressure conditions [48].

Volumetric Property study: A comprehensive volumetric think about discovered varieties in VMA, VFA, and VTM, and it was anticipated that SMA's considerably high VFA and low VTM would enhance the strength and rutting resistance performance and decrease susceptibility to ruts and moisture damage [49].

4 RESULTS AND DISCUSSION

4.1 Stability and Volumetric Properties of SMA and CMA

In table 5, the taking after tables demonstrate the research facility investigation outcomes, consisting of the Marshall Steadiness and Stream test, volumetric examination, and rutting resistance modeling. This investigation indicates that SMA and CMA demonstrative critical contrasts with regards to their solidness, thickness, stream, and overall performance under simulated traffic loads.

Table 5 Marshall Stability and Flow Values of SMA and CMA

Asphalt Type	Stability (kN)	Flow (mm)	Density (g/cm³)
SMA	15.8	3.2	2.34
CMA	10.6	2.7	2.28

In table 6, it is discovered from the Marshall Soundness Test that SMA is much more steady than CMA. The sorter steadiness esteem of SMA (15.8 kN) advance proposes the consequent resistance to plastic distortion under stack which is decisive for the traffic loadings of asphalts. While SMA has significantly higher stream values, they are still within reasonable for high-traffic asphalts indicating that it can be useful where such surfaces are needed. CMA incorporates less thickness to some extent than SMA, which is related to its heightened solidity and compact composition[50].

Table 6 Volumetric Properties of SMA and CMA

Asphalt Type	Voids in Mineral Aggregate (VMA, %)	Voids Filled with Asphalt (VFA, %)	Air Voids (VTM, %)
SMA	17.5	80	3.0
CMA	15.2	75	4.0

In table 7, SMA from the volumetric properties looks to have bigger values of Voids in Mineral Aggregate (VMA) and Voids Filled with Asphalt (VFA) than CMA. The blend characterization is fundamental to the life span and performance of the black-top blend. The study also reveals how the VFA of SMA is 80 % far superior to the FEA, which indicates far better binder distribution that in turn results in constant rutting resistance plus long-term stability. Also, SMA contains a lesser amount of Air Voids (VTM) substance of 3.0%, compared with CMA at 4.0%, hence a slightly denser and stable mix which is advantageous in reducing early aging and water entrance [10, 51].

Table 7 Binder Drainage and Stiffness Values of SMA and CMA

Asphalt Type	Binder Content (%)	Binder Drainage (%)	Stiffness (N/mm)
SMA	6.8	0.2	1500
CMA	5.2	0.8	1200

In table 8, CMA tests had a smaller, binder concentration (5.2%) than SMA tests (6.8%) which created a difference to increase cohesiveness and LSM to guess for binder wastage. SMA exhibits the least folio waste amounting to 0.2% and its textual reliability and media adroitness to rutting beneath the stack improves. SMA's greater firmness (1500 N/mm) proves its thatch to bear greater distortion under heavy loads indicating its suitability for higher stress asphalts. On the other hand, CMA exhibits improved binder drainage (0.8%) and lower stiffness which could limit its use in high-traffic areas[19, 23].

Table 8 Comparative Rutting Resistance of SMA and CMA under Simulated Traffic Loads

Load Cycles	Rut Depth - SMA (mm)	Rut Depth - CMA (mm)
5,000	1.5	2.3
10,000	2.8	4.0
20,000	3.6	5.7
50,000	5.1	7.9

The result showing the rutting resistance simulation with an increase in load cycles has revealed that SMA has better performance than CMA. At all stages, SMA possessed significantly lower rut depths, and this revealed that SMA was less susceptible to durably ongoing deformation known as rutting under applied traffic loads. In 50,000 load cycles, SMA has a rutting of 5.1mm as compared with CMA's 7.9mm, this shows that SMA is malleable to high-traffic roads and has long serviceability [14, 52].

4.2 Discussion

From this study, the performance of Stone Mastic Asphalt (SMA) is proved to be more resistant than Conventional Asphalt (CMA) instability, volumetric properties, and resistance to rutting under passes traffic loads. SMA has higher stability values than DOC and better resistance to deformation and hence can be used on high-stressed pavements, especially in areas with heavy traffic.

Due to SMA containing a higher proportion of binder and a minimum binder drainage rate, it enhances cohesiveness to moisture, reduces binder loss, and exhibits better resistance against water seepage to advance durability and performance. In addition, it was also observed that the rutting stress of SMA material under traffic cycle simulation was higher than that of the control sample, suggesting that SMA is capable of handling long-term stress and should ideally be incorporated in roads that experience a high traffic load, especially in urban areas. Even the volumetric analysis supports the fact that SMA has higher VMA and VFA, which represents a better binder-to-aggregate ratio leading to more pavement stability and longer durability. SMA's denser particle packing is evidenced by a smaller air void percentage and this has a positive impact on SMA's performance, especially in resistance to water-related damages and aging. At last, the results of this research show that SMA performs over CMA in stability, volumetric properties as well as resistance to rutting which may mean that SMA is more suitable on high-traffic roads. But SMA, containing a higher quantity of binder and stabilizing fibers, is slightly expensive and a potential cost factor for which the right combination for pavement construction needs to be considered.

5 CONCLUSION

This study looks at Stone Mastic Asphalt (SMA) and compares it with Conventional Mix Asphalt (CMA) in areas of stability, volumetric properties, and performance under varied conditions. The laboratory essays such as Marshall stability value, and volumetric studies also substantiate that SMA is a material of superior stability, rutting resistivity, and long-term demeanor.

Superior Performance: Compared to CMA, SMA is 50% higher in terms of Marshall Stability while having better rut resistance perfect for heavily trafficked roads.

Enhanced Durability: SMA has greater VMA, lower air voids, and less binder drainage capability which confirms better long-term stabilities and performance.

Cost-Effectiveness: Though SMA possesses higher installation costs, it will last longer compared to PV and has fewer maintenance costs in the long run.

Application Suitability: SMA should be employed in areas where the load is big, and there is a heavy stream of traffic while CMA can be used where the load is comparatively low.

Future Research: Future research on how improvements in SMA when arising out of recycled material and other studies that seek to establish the environmental impact of SMA will bring down the usage costs and improve sustainability.

Hence, SMA is preferable for high-traffic pavement schemes because of its tougher, more stable structure together with marginal performance benefits.

6 RECOMMENDATIONS

Consequently, the results elucidate that, based on higher stability, rutting performance, and durability, Stone Mastic Asphalt (SMA) should be more appropriate for heavy traffic and high-stress areas. When using SMA mix designs, the usage of material that can be reclaimed such as Reclaimed Asphalt Pavement (RAP), proves to be more cost-effective. Consequently, these activities call for close supervision and servicing for improved durability and reduced recurrent costs over time. Additional research should also involve the ecological benefits of SMA and overall cost sustainability in the future. CAM could be cheaper in low-traffic areas if it complies with the required wearing course toughness characteristics. They will enhance pavement performance and reduce overall Life Cycle Costs; they will also increase the sustainability of the pavements thus the overall road network.

AUTHORS' CONTRIBUTIONS

Investigations were conducted by Adnan, and the methodology was developed by both Adnan and Abdullah Khan Writing, review, editing, and supervision were overseen by Adnan, and the Introduction and software were done by Aftab Ali Khan and Abdullah khan. The completed paper has been seen and approved by all authors.

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ABBREVIATIONS

SMA: Stone Mastic Asphalt
CMA: Conventional Mastic Asphalt

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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