Sample Integrating Marble and Granite Waste as Eco-Friendly Substitutes for Stone Dust in Stone Matrix Asphalt (SMA) Mixes

Ankush Tiwari[1], Vivek Kumar[2]

[1]*FResearch Scholar, Department of Civil Engineering, Mewar University, Chittorgarh, Rajasthan*
[2]*SAssisatnt Professor, Department of Civil Engineering, Mewar University, Chittorgarh, Rajasthan*

---***---

Abstract - Stone Matrix Asphalt (SMA) is a rut-resistant gap-graded bituminous mixture in which coarse aggregate interlock, rich mastic, and stabilizing additives collectively govern performance. This manuscript reformats the uploaded thesis into a journal-style paper and evaluates the feasibility of using marble cutting waste and granite cutting waste as eco-friendly substitutes for conventional stone dust in SMA wearing-course mixtures. Three mixes were compared: a control SMA with stone dust, an SMA with 20% stone dust and 80% marble waste, and an SMA with 20% stone dust and 80% granite waste. Laboratory assessment covered Marshall stability, flow value, air voids, voids in mineral aggregate, bulk density, indirect tensile strength, tensile strength ratio, and drain-down characteristics. VG-30 binder, lime filler, cellulose fiber (0.3% by aggregate mass), and MoRTH-compliant gradation were used. The control Marshall design indicated an optimum binder content of about 6.17%, while the comparative performance discussion in the thesis adopted 6.0% binder content for the sample-to-sample evaluation. Across the comparative tests, the marble-waste SMA exhibited the highest Marshall stability, the lowest air voids and drain-down, the highest bulk density, and the best indirect tensile performance. Granite-waste SMA also outperformed the control mix for most mechanical indicators, although its drain-down value remained higher than the marble-waste mixture. The results support the technical viability of marble and granite waste as sustainable fine-aggregate substitutes in SMA, with marble waste showing the most balanced overall performance in this study.

***Key Words*: Stone matrix asphalt; marble waste; granite waste; stone dust replacement; Marshall stability; indirect tensile strength; drain-down; sustainable pavement materials.**

1. INTRODUCTION

Stone Matrix Asphalt has been widely adopted for high-stress surfacing applications because its stone-on-stone skeleton gives superior resistance to rutting and permanent deformation when compared with conventional dense-graded hot-mix asphalt. At the same time, dimensional stone processing produces very large quantities of marble and granite powder that create disposal, land occupation, dust, and water-pollution problems, particularly in Rajasthan, India. Reusing these waste streams in asphalt mixtures addresses two engineering needs simultaneously: reducing environmental burden and conserving natural fine-aggregate resources.

The uploaded thesis investigates whether marble and granite cutting waste can replace conventional stone dust in SMA without compromising functional or mechanical performance. The study compares a control mixture with two alternative fine-aggregate systems and evaluates the resulting Marshall, volumetric, tensile, moisture-resistance, and drain-down characteristics.

2. Literature Survey

Table -1: Table: Summary of Literature on Flexible Pavements, Stone Matrix Asphalt and Waste Mineral Fillers

Category	Aspect / Study	Key Findings and Engineering Significance
Flexible Pavement System	Surface, base and sub-base layers	Multilayer flexible pavements distribute traffic loads efficiently; surface layer provides skid resistance, riding quality, waterproofing and rut resistance.
Bituminous Mixture Types	Dense-graded, open-graded and HMA	Dense graded mixes provide strength and durability; open graded mixes enhance drainage; HMA widely adopted due to superior field performance.
Stone Matrix Asphalt Structure	Gap-graded aggregate skeleton	High coarse aggregate content creates stone-to-stone contact improving rutting resistance and load carrying capacity.
Binder Characteristics in SMA	High binder content (>6%) with mineral filler (~10%)	Enhances fatigue resistance, durability and flexibility; reduces permeability and ageing.

Category	Aspect / Study	Key Findings and Engineering Significance
Air Void Characteristics	Low air voids (3–4%)	Improves waterproofing and increases pavement service life.
Surface Texture	Rough macrotexture of SMA	Improves skid resistance, surface drainage, safety and reduces tyre–pavement noise.
Advantages of SMA	Rut resistance, fatigue life and durability	Studies report 30–40% lower permanent deformation and 3–5 times higher fatigue life than dense graded asphalt mixtures.
Limitations of SMA	Higher initial cost and binder drain-down	Requires stabilizing additives and strict quality control during production and construction.
Life Cycle Cost Studies	Georgia DOT and Alaska DOT analyses	Higher initial cost offset by longer service life (5–10 years additional performance).
Field Performance Studies	USA and Indian trial sections	SMA performs effectively under heavy traffic and varying climatic conditions.
Industrial Waste Fillers	Marble dust and granite dust usage	Improves soil gradation, density, shear strength and swelling resistance; promotes sustainable construction.
Ishai et al.	Filler–bitumen mastic study	Optimum filler proportion improves mechanical performance of asphalt mixtures.
Karasahin and Terzi	Marble dust filler	Performance comparable to limestone filler; suitable for low to medium traffic roads.
Sharma et al.	Fly ash filler	Up to 7% filler can be incorporated without performance deterioration.
Misra	Marble slurry stabilization	Improves compaction and load bearing capacity of subgrade soils.
Mishra et al.	Granite dust stabilization	Significant reduction in plasticity index and swelling of expansive soils.

2.1. Research Gap

Although numerous studies have examined marble waste, quarry dust, and other industrial by-products in pavement applications, relatively fewer investigations have focused specifically on the combined use of Kota stone waste and marble waste across multiple pavement layers such as GSB, WMM, and BM under a uniform testing framework. In particular, there remains a need for systematic comparison of their influence on MDD, OMC, CBR, Marshall stability, and strength parameters at varying replacement levels. Recent studies confirm the broad feasibility of stone-waste reuse, but they also show that optimum performance is highly dependent on dosage and application layer, which justifies further experimental investigation of these materials in the context of flexible pavement construction.

3. Materials & Methodology

Three SMA mixtures were examined in the underlying thesis: a control mixture using stone dust as the fine aggregate fraction, a mixture using 20% stone dust and 80% marble cutting waste, and a mixture using 20% stone dust and 80% granite cutting waste. Crushed coarse aggregates were used to develop the stone skeleton. VG-30 bitumen was used as the binder, lime was used as mineral filler, and cellulose fiber at 0.3% by aggregate mass was incorporated as a stabilizing additive to limit drain-down and improve mastic stability.

Table 2. Constituent materials used in the SMA mixtures.

Material	Specification / source	Role in SMA mixture
Coarse aggregates	Crushed aggregates meeting SMA requirements	Provide stone-on-stone skeleton and rut resistance

Material	Specification / source	Role in SMA mixture
Fine aggregate system	Stone dust / marble waste / granite waste	Fill inter-particle voids and influence mortar behavior
Binder	VG-30 bitumen	Coat aggregates and provide cohesion
Mineral filler	Lime	Increase mortar stiffness and improve stability
Stabilizer	Cellulose fiber at 0.3% by aggregate mass	Control drain-down and improve mastic stability

3.2 Material characterization and test standards

The thesis reports that the marble cutting waste had a specific gravity of 2.84 and the granite cutting waste had a specific gravity of 2.66; both were non-plastic. Aggregate characterization included impact value, Los Angeles abrasion, flakiness and elongation index, water absorption, and specific gravity. Binder characterization included penetration, softening point, ductility, and specific gravity in accordance with relevant Indian standards. The reported properties of the aggregate and binder satisfied the acceptance limits adopted for the study.

Table 2. Key material characterization results reported in the thesis.

Test item	Reported result	Adopted limit / note
Aggregate impact value	16.54	< 18
Los Angeles abrasion value	21.8	< 25
Combined flakiness + elongation index (%)	26.6	< 30
Coarse aggregate specific gravity	2.81	2.6–2.9
Fine aggregate specific gravity	2.41	Reported in thesis
Bitumen penetration at 25°C (0.1 mm)	65	> 45
Bitumen ductility (cm)	85	> 40
Bitumen softening point (°C)	49	Meets study requirement

3.3 Mix design and experimental program

The aggregate gradation was selected according to the SMA requirements adopted in the thesis and consistent with IRC: SP-79. Marshall mix design was conducted by varying binder content from 5.0% to 7.0%. The control mixture was used to establish the optimum binder content based on maximum stability, maximum bulk density, and the 4% air-void criterion.

The experimental evaluation included Marshall stability, flow value, air voids, voids in mineral aggregate (VMA), bulk density, indirect tensile strength (ITS), tensile strength ratio (TSR), and drain-down. For comparison across the three fine-aggregate systems, the thesis discussed the mixture performance at 6.0% binder content.

Table 3. Experimental program adopted for the SMA mixtures.

Parameter	Testing / basis	Purpose
Marshall stability and flow	Marshall method	Assess strength and deformation behavior
Air voids and bulk density	Volumetric analysis	Assess compactness and mix structure
VMA and VFB trend	Marshall design evaluation	Support optimum binder content selection
Indirect tensile strength	Unconditioned and conditioned specimens	Assess tensile resistance and moisture sensitivity

Parameter	Testing / basis	Purpose
TSR	Ratio of conditioned to unconditioned ITS	Assess retained strength after conditioning
Drain-down	Wire basket / catch plate method	Assess mastic stability at elevated temperature

4. Results and Discussion

The Marshall design trends of the control SMA showed the expected behavior with increasing binder content. Flow value and voids filled with bitumen increased as binder content increased, while air voids decreased because the additional binder occupied internal void space. Stability peaked in the medium-to-high binder-content range, and bulk density rose to a maximum before decreasing with excess binder. Based on the average of the binder content corresponding to maximum stability (6.5%), maximum bulk density (5.5%), and 4% air voids (6.5%), the optimum binder content of the control SMA was calculated as 6.17%.

4.2 Comparative performance of the three SMA mixtures

Table 4 summarizes the key comparative performance indicators of the control, marble-waste, and granite-waste SMA mixtures at the binder content used for the comparative discussion in the thesis. The marble-waste SMA showed the strongest overall performance across the measured properties.

Table 4. Comparative performance of the control and waste-modified SMA mixtures.

Mix type	Marshall stability (kg)	Air voids (%)	Flow (mm)	Bulk density (g/cc)	ITS, uncond. (kPa)	ITS, cond. (kPa)	TSR	Drain-down (%)
Stone dust (control)	1180	4.33	3.5	2.386	737.58	610.42	0.86	0.17
20% stone dust + 80% marble waste	1280	3.88	3.1	2.397	836.35	712.10	0.88	0.13
20% stone dust + 80% granite waste	1210	4.11	3.3	2.392	788.45	661.284	0.87	0.21

The marble-waste SMA achieved the highest Marshall stability (1280 kg), indicating the greatest load-carrying capacity and resistance to deformation among the three mixtures. Its lower flow value and lower air void content suggest a denser and more stable internal structure. The same mixture also produced the highest bulk density, which supports the inference of improved compactness.

The tensile performance results reinforce this observation. The marble-waste SMA recorded the highest unconditioned ITS (836.35 kPa) as well as the highest conditioned ITS (712.10 kPa), leading to the highest TSR value of 0.88. This indicates better retained strength under moisture conditioning and implies improved resistance to moisture-induced damage. Granite-waste SMA also outperformed the control mixture in both unconditioned and conditioned ITS, although its response remained intermediate between the control and marble-waste mixtures.

Drain-down behavior is particularly important in SMA because the rich mortar and gap-graded structure increase the risk of binder migration during mixing, transport, and placement. The marble-waste mixture showed the lowest drain-down value (0.13%), while the granite-waste mixture recorded the highest drain-down value (0.21%). These results suggest that marble waste provided a more favorable balance between fine-particle packing and mortar stabilization under the conditions of the study.

4.3 Engineering interpretation and sustainability implications

Overall, the results indicate that replacing most of the conventional stone dust fraction with marble waste or granite waste did not degrade the essential SMA performance parameters. Instead, both waste-derived mixtures improved several critical indicators relative to the control. The likely explanation, as discussed in the thesis, is that the finer waste particles contributed to improved filling of voids, better internal packing, and stronger interaction within the binder–filler mortar.

From a sustainability perspective, the findings are significant because they convert a major industrial waste stream into a functional pavement material. This reuse strategy can reduce reliance on virgin fine aggregate and lower the environmental burden associated with waste disposal. Within the investigated range, marble waste delivered the most balanced performance in terms of stability, compactness, tensile resistance, moisture retention, and drain-down control.

5. Practical Significance, Limitations, and Future Work

The study demonstrates that stone-processing wastes can be considered technically viable materials for SMA wearing courses, particularly in regions where marble and granite industries produce large quantities of powder waste. The results are relevant to pavement engineers seeking both improved surface-course performance and sustainable material alternatives.

A key limitation acknowledged in the thesis is that the same binder content was used for comparative evaluation of all replacement mixtures. Because marble waste and granite waste differ in particle size distribution, texture, surface area, and absorption behavior, the optimum binder content may differ for each mixture. Consequently, the comparative results should be interpreted as technically indicative rather than as a fully optimized mixture design for every replacement system.

Future work should therefore include separate optimum-binder-content determination for each replacement mix, broader replacement percentages, rutting and fatigue performance under repeated loading, long-term moisture susceptibility, and field-scale validation. Cost analysis and life-cycle assessment would also strengthen the practical case for large-scale implementation.

6. Conclusions

• Both marble-waste and granite-waste SMA mixtures improved key performance indicators relative to the control stone-dust SMA.
• The marble-waste SMA produced the highest Marshall stability, lowest air voids, highest bulk density, highest indirect tensile strength in conditioned and unconditioned states, highest TSR, and lowest drain-down among the tested mixtures.
• Granite-waste SMA also improved stability and tensile response compared with the control mixture, confirming its suitability as an alternative fine aggregate in SMA.
• The control Marshall design yielded an optimum binder content of 6.17%; however, the thesis notes that separate optimum binder content determination for each replacement system remains an important next step.
• The study supports the technical feasibility of reusing marble and granite cutting wastes in SMA wearing courses, with marble waste showing the most favorable overall balance of properties in the investigated range.

REFERENCES

[1] Brown, E. R., Haddock, J. E., and Mallick, R. B., Stone Matrix Asphalt: Design and Construction, National Asphalt Pavement Association (NAPA), Lanham, Maryland, USA, 1997.

[2] National Asphalt Pavement Association (NAPA), Designing and Constructing Stone Matrix Asphalt Mixtures, Information Series 122, Maryland, USA, 1999.

[3] Austroads, Stone Mastic Asphalt Guide, Sydney, Australia, 1993.

[4] Michaut, M., “Stone Mastic Asphalt in Europe,” European Asphalt Pavement Association Report, Brussels, Belgium, 1995.

[5] Australian Standard AS 2150, Hot Mix Asphalt – A Guide to Good Practice, Standards Australia, Sydney, 1995.

[6] Brown, E. R., and Cooley, L. A., “Design of Stone Matrix Asphalt Mixtures,” Transportation Research Record, No. 1789, pp. 15–22, 2003.

[7] Ibrahim, M. R., “Performance Characteristics of Stone Matrix Asphalt Pavements,” Journal of Materials in Civil Engineering, ASCE, Vol. 17, No. 3, pp. 256–262, 2005.

[8] Schmiedlin, R. B., and Bischoff, D. L., “Performance Evaluation of Stone Matrix Asphalt in the United States,” Transportation Research Record, No. 1813, pp. 44–52, 2002.

[9] Nunn, M. E., “Long-Term Performance of SMA Surfacing,” TRL Report, Transportation Research Laboratory, UK, 1994.

[10] Watson, D. E., and Jared, D. M., “Performance Evaluation of Stone Matrix Asphalt,” Transportation Research Record, No. 1492, pp. 1–8, 1995.

[11] Huang, Y. H., Pavement Analysis and Design, 2nd Edition, Pearson Education, New Delhi, 2004.

[12] Tayfur, S., Ozen, H., and Aksoy, A., “Investigation of Rutting Performance of Asphalt Mixtures Using Indirect Tensile Strength Test,” Construction and Building Materials, Vol. 21, No. 2, pp. 286–291, 2007.

[13] Zhang, J., Cooley, L. A., and Kandhal, P. S., “Fatigue Performance of Asphalt Mixtures,” Journal of Transportation Engineering, ASCE, Vol. 127, No. 5, pp. 373–381, 2001.

[14] Behbahani, H., Ayazi, A., and Moniri, A., “Laboratory Evaluation of Fatigue and Rutting Resistance of Asphalt Mixtures,” Construction and Building Materials, Vol. 23, No. 8, pp. 2821–2827, 2009.

[15] Ishai, I., Livneh, M., and Shklarsky, E., "Effect of Filler Type and Content on Asphalt Mix Properties," Journal of the Association of Asphalt Paving Technologists, Vol. 49, pp. 34–56, 1980.

[16] Karasahin, M., and Terzi, S., "Evaluation of Marble Waste Dust in Asphalt Mixtures," Construction and Building Materials, Vol. 21, No. 3, pp. 616–620, 2007.

[17] Sharma, A., Yadav, R. K., and Jain, P. K., "Utilization of Fly Ash in Bituminous Concrete Mixes," Journal of Materials in Civil Engineering, ASCE, Vol. 22, No. 5, pp. 480–486, 2010.

[18] Misra, A. K., "Use of Marble Slurry Dust in Road Construction," Central Road Research Institute (CRRI) Report, New Delhi, India, 2010.

[19] Arora, K. R., "Effect of Marble Powder on Engineering Properties of Soil," International Journal of Civil Engineering Research, Vol. 5, No. 2, pp. 151–160, 2014.

[20] Mishra, J., Gupta, A., and Kumar, S., "Stabilization of Expansive Soil Using Granite Dust," International Journal of Pavement Engineering, Vol. 15, No. 4, pp. 321–330, 2014.

[21] Chen, J. S., and Huang, C. C., "Engineering Properties of Stone Matrix Asphalt Containing Fibers," Journal of Materials in Civil Engineering, ASCE, Vol. 20, No. 2, pp. 123–130, 2008.

[22] Indian Roads Congress, Tentative Specifications for Stone Matrix Asphalt, IRC: SP-79, New Delhi, India, 2008.

[23] Ministry of Road Transport and Highways (MoRTH), Specifications for Road and Bridge Works, 5th Revision, New Delhi, India, 2001.