Performance of Hot Mix Asphalt Using Blended Cinder–Basalt Aggregates for Low-Volume Roads in Mbeya Region, Tanzania

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DOI: https://doi.org/10.47772/IJRISS.2026.10200004

Received: 04 February 2026; Accepted: 10 February 2026; Published: 21 February 2026

ABSTRACT

The limited availability of high-quality aggregates in volcanic regions has increased interest in using locally available marginal materials for asphalt pavement construction. This study evaluates the suitability of blended cinder–basalt–sand aggregates for AC20 hot mix asphalt (HMA) surfacing of sealed low-volume roads in Mbeya Region, Tanzania. Physical and mechanical properties of cinder, basalt, and blended aggregates were determined, followed by Marshall mix design using 60/70 penetration grade bitumen.

Natural cinder aggregates exhibited inadequate strength and durability, with low ten percent fines values and high crushing values, confirming their unsuitability for direct use in HMA. Blending with basalt significantly improved aggregate performance, with ten percent fines values increasing to 128–202 kN and aggregate crushing values reducing to 12.5–19%. Marshall test results showed that all blended mixtures satisfied specification requirements, with stability values of 10–12 kN, flow values of 2.5–3 mm, air voids of 4–7%, and voids in mineral aggregate of 18.5–22.4%. Optimum binder content increased with cinder content, ranging from 6.7% to 8.6%, reflecting the porous nature of cinder aggregates.

The results of this study are based solely on Marshall mix design parameters and are therefore specific to low-volume road applications under moderate environmental exposure conditions. Performance-related properties such as moisture susceptibility, rutting resistance, and aging behavior were not evaluated and require further investigation before broader application.

Keywords: Hot Mix Asphalt, Cinder Aggregates, Basalt Aggregates, Low-Volume Roads, Marshall Mix Design, Tanzania

INTRODUCTION

Aggregates constitute more than 90% of hot mix asphalt (HMA) by weight and play a dominant role in determining pavement strength, durability, and long-term performance (Speight, 2016). In many developing regions, the availability of high-quality crushed stone is limited, resulting in increased construction costs due to long haul distances. This challenge is particularly evident in volcanic regions, where locally available aggregates such as cinder gravels are abundant but often classified as marginal materials.

Low-volume roads (LVRs) form a substantial portion of road networks in sub-Saharan Africa and are typically designed for low traffic loading (MoWTC, 2016). Asphalt surfacing is increasingly adopted for LVRs due to improved ride quality and reduced maintenance compared to unsealed roads. However, the high cost of conventional aggregates remains a major constraint to wider application. Mbeya Region, located within the East African Rift System, contains extensive deposits of volcanic cinder (Fontijn et al., 2012), presenting an opportunity for sustainable use of local materials if their engineering limitations can be addressed.

Previous studies have shown that cinder aggregates are porous, lightweight, and mechanically weak, exhibiting low resistance to crushing and high water absorption (Hearn et al., 2018; Seyfe and Geremew, 2019). These properties generally prevent their direct use in asphalt concrete under standard specifications such as those of the Tanzania Ministry of Works (MoW, 2000b). Several researchers have demonstrated that blending marginal aggregates with stronger crushed stone materials can significantly improve their mechanical performance and durability (Berhanu, 2015; Chengula and Mnkeni, 2021; Chengula, 2022). While such approaches have been applied successfully in unbound and stabilized pavement layers, limited research has focused on the use of blended volcanic aggregates in HMA surfacing, particularly using standard Marshall mix design procedures.

In addition, specification limits for asphalt mixtures are typically developed based on dense, non-porous aggregates and may not adequately reflect the behavior of porous volcanic materials. Higher binder contents are often required to compensate for absorption, raising concerns regarding cost and durability (Sabita, 2011). For low-volume roads, however, higher binder contents may be acceptable if stability and volumetric requirements are satisfied.

This study investigates the feasibility of using blended cinder–basalt–sand aggregates for AC20 HMA surfacing of sealed low-volume roads. The objectives are to:

i. Characterize the physical and mechanical properties of natural cinder aggregates;

ii. Evaluate the improvement in aggregate performance achieved through blending with basalt and sand; and

iii. Assess the Marshall stability and volumetric performance of asphalt mixtures produced using blended aggregates.

To improve transferability and clarity of scope, this study considers sealed low-volume roads carrying traffic typically less than 1 million equivalent standard axles (ESA) over the design life, consistent with Tanzanian LVR guidelines (MoWTC, 2016; Mwita, et al,. 2024). The climatic conditions in Mbeya Region are characterized by moderate to high rainfall and temperature variations typical of highland tropical environments. These traffic and environmental assumptions are important in interpreting the applicability of the findings.

While Marshall mix design remains widely adopted in Tanzania for low-volume roads, it does not directly evaluate durability-related performance such as moisture damage resistance, rutting susceptibility, or long-term oxidative aging. This methodological limitation is explicitly acknowledged, and the conclusions of this study should be interpreted within this framework.

MATERIALS AND METHODS

Cinder and basalt aggregates were obtained from Ituha quarry in Mbeya Region, while natural sand was sourced from the Mbalizi River. A 60/70 penetration grade bitumen was used as the binder. Aggregate characterization included particle size distribution, specific gravity, water absorption, ten percent fines value (TFV), aggregate crushing value (ACV), aggregate impact value (AIV), and particle shape indices, conducted in accordance with relevant MoW, ASTM, AASHTO, and BS standards (MoW, 2000a, b).

RESULTS AND DISCUSSION

Aggregate Properties

The physical and mechanical properties of the source aggregates are summarized in **Table 1**. Natural cinder aggregates exhibited low strength and durability, characterized by low TFV, high ACV and AIV values and high-water absorption. These results confirm previous findings that cinder aggregates are unsuitable for direct use in asphalt surfacing (Hearn et al., 2018; Seyfe and Geremew, 2019). In contrast, basalt aggregates satisfied all specification requirements, demonstrating high resistance to crushing and low absorption, consistent with earlier studies on high-quality crushed stone aggregates (Speight, 2016).

Table 1. Physical and mechanical properties of cinder, basalt, and sand aggregates used in the study

Property	Cinder	Basalt	Sand	Specification Limit
Specific Gravity	2.21	2.67	2.62	–

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue II February 2026

Water Absorption (%)	3.6	1.1	1.4	≤2.0
ACV (%)	27.2	12.1	–	≤20
AIV (%)	26.3	11.6	–	≤20
TFV (kN)	86	228	–	≥110

Effect of Blending on Aggregate Performance

The mechanical properties of blended cinder–basalt aggregates are presented in **Table 2**, while the particle size distributions of source and blended aggregates are shown in **Fig. 1**. Blending cinder with basalt and sand significantly improved aggregate performance. Blends containing higher proportions of basalt achieved TFV values exceeding 110 kN and ACV values below 17%, satisfying AC20 asphalt concrete requirements (MoW, 2000b). The improvement is attributed to reduced overall porosity and improved particle interlocking provided by the basalt aggregates, consistent with observations reported by Berhanu (2015) and Chengula (2022).

Table 2: Mechanical properties of blended cinder–basalt aggregates for AC20 asphalt concrete

Blend (%)	TFV (kN)	ACV (%)	AIV (%)
20%Cinder+80%Basalt	202	12.5	12.0
40%Cinder+60%Basalt	176	14.8	14.2
60%Cinder+40%Basalt	145	17.0	16.8
80%Cinder+20Basalt	128	19.3	18.3

The progressive improvement in TFV and reduction in ACV with increasing basalt content confirms the structural contribution of stronger basalt particles within the aggregate skeleton. However, although blending improves mechanical strength indices, the high intrinsic porosity and absorption of cinder aggregates remain significant concerns. Elevated absorption (3.6%) suggests potential vulnerability to moisture-induced damage, particularly stripping at the binder aggregate interface. Since moisture susceptibility tests such as Tensile Strength Ratio (TSR) were not conducted, the long-term resistance of the blends to moisture damage cannot be conclusively established. This represents an important methodological gap and an area for future research.

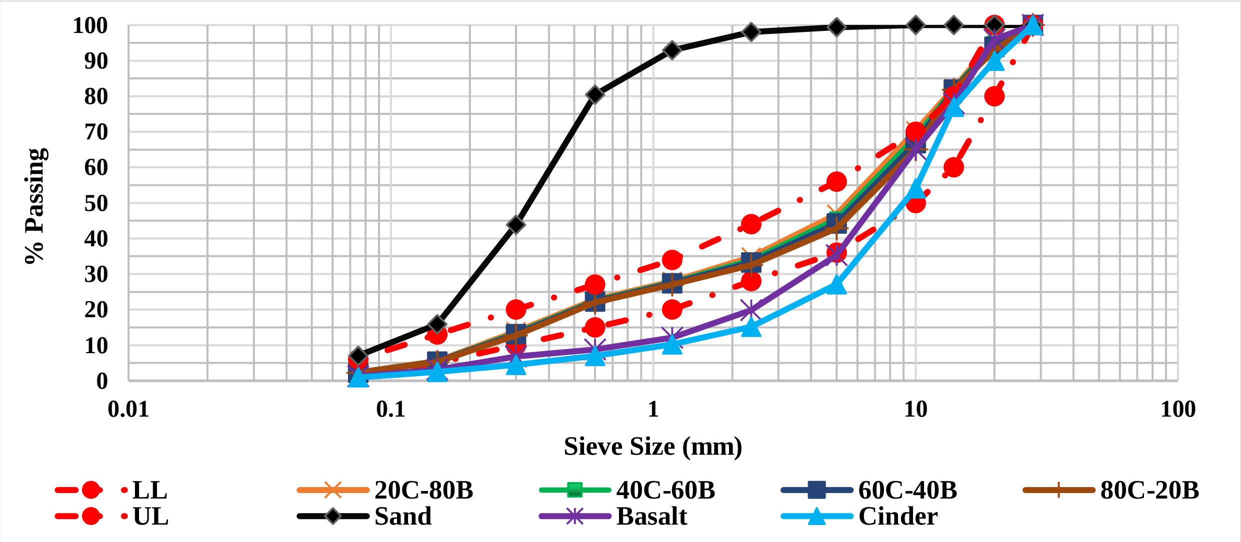

Figure 1. Particle size distribution of cinder, basalt, sand, and blended aggregates compared with AC20 specification limits

Marshall Mix Performance

The Marshall properties of asphalt mixtures at optimum binder content are summarized in **Table 3**, while the variation of volumetric and mechanical properties with binder content is illustrated in **Figs. 2 and 3**. All blended asphalt mixtures satisfied Marshall stability, flow, and volumetric criteria specified for low-volume roads (MoW, 2000b). Marshall stability values increased from 10 to 12.3 kN, indicating improved aggregate interlock and load distribution.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue II February 2026

However, the interpretation of these trends must be critically examined beyond simple confirmation of specification compliance. The air voids ranged from 4 to 7%, and VMA values ranged from 18.5 to 22.4%.

The optimum binder content (OBC) increased significantly with increasing cinder content (6.7%–8.6%) a similar trend reported for asphalt mixtures incorporating porous volcanic aggregates (Sabita, 2011) which reflects the absorptive nature of cinder aggregates. While higher binder content ensures adequate coating and volumetric compliance, it may increase susceptibility to bleeding under elevated temperatures, reduced rutting resistance under slow-moving traffic and accelerated oxidative aging due to higher exposed binder volume.

These potential trade-offs were not evaluated in this study and should be considered in practical applications. Due to high absorptive nature of cinder aggregates, there is increased risk of moisture entrapment and stripping during service life of the pavements. Without standardized moisture damage testing (e.g., AASHTO T283 TSR or boiling test), durability under wet conditions cannot be fully assessed.

However, Marshall stability provides an indirect measure of load resistance but does not adequately predict rutting performance under repeated traffic loading. Performance-based tests such as wheel tracking or dynamic modulus testing would provide stronger evidence of long-term behavior. For this study the influence of elevated binder content on oxidative hardening and long-term stiffness was not investigated. Porous aggregates may accelerate binder aging due to increased binder absorption and surface exposure. Thus, while Marshall criteria were satisfied, further Marshall performance evaluation studies are required for field application beyond low-volume, low-stress environments.

Table 3. Performance of hot mix asphalt incorporating blended cinder–basalt aggregates for low-volume roads

Blend (%)	Optimum Binder Content (%)	Marshall Stability (kN)	Flow (mm)	Air Voids (%)	VMA (%)	VFA (%)
20%Cinder+80%Basalt	6.7	12.3	2.50	4.2	18.5	77.3
40%Cinder+60%Basalt	7.4	11.1	2.66	5.81	21.3	72.7
60%Cinder+40%Basalt	8.0	10.8	2.68	7.6	22.1	67.4
80%Cinder+20Basalt	8.6	10.1	2.82	7.3	22.4	67.2

Stability increases with basalt content, reaching **12.3 kN** at 80% basalt, indicating a well-interlocked aggregate skeleton. Flow values (2–3 mm) remain within acceptable low-volume road limits. Air voids and VMA decrease as basalt content rises due to denser packing. OBC decreases with increasing basalt because porous cinder absorbs more binder. The **40–60% basalt blend** provides optimal balance of strength, volumetric performance, and cost-effective binder use.

Therefore, the use of locally available cinder aggregates presents potential economic advantages by reducing haulage distances associated with importing high-quality crushed basalt. However, the increased binder demand associated with higher cinder contents may partially offset these savings.

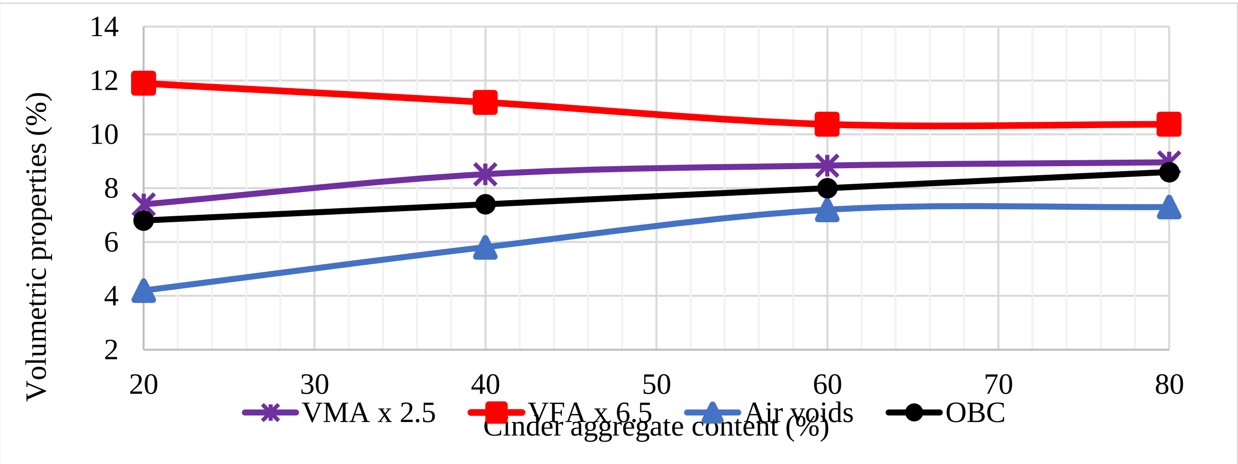

Figure 2. Variation of air voids, voids in mineral aggregate (VMA), and voids filled with asphalt (VFA), Optimum binder content (OBC) of blended asphalt mixtures with Cinder content

In this regard, a quantitative cost–benefit analysis should be conducted to analyze material buying and transport costs, incremental binder cost due to higher OBC and life-cycle maintenance implications.

Such analysis would provide stronger evidence on cost-effectiveness of using cinder aggregates for HMA mixes.

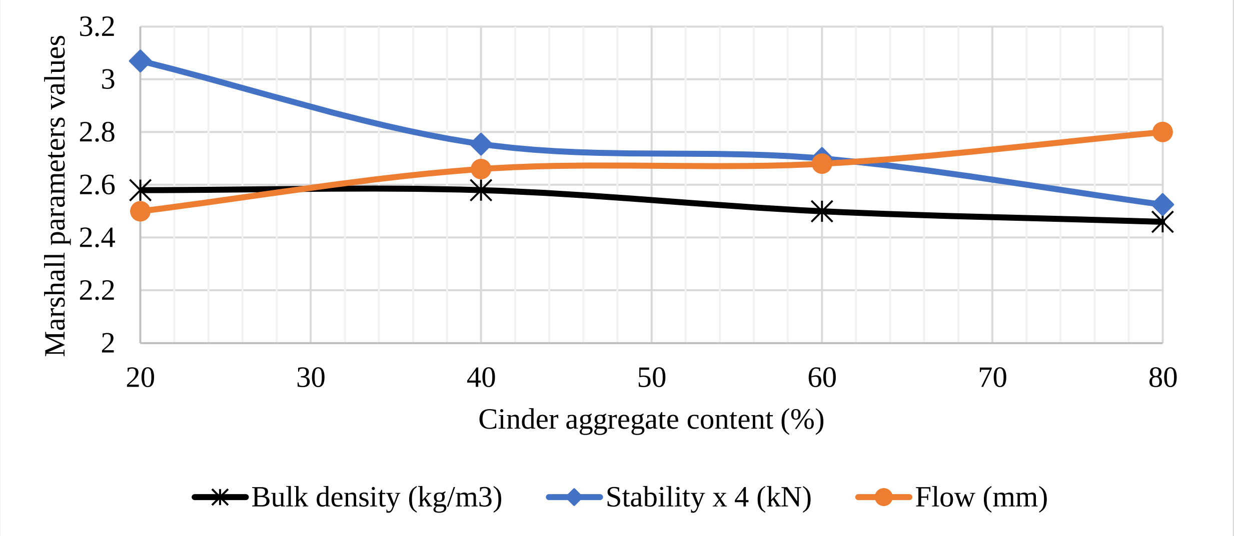

Figure 3. Effect of Cinder content on bulk density, Marshall stability, and flow of blended asphalt mixtures

CONCLUSIONS

The conclusions presented herein are based on laboratory evaluation using Marshall mix design procedures and are therefore limited to low-volume road applications under moderate traffic and environmental exposure conditions**.**

1. Natural cinder aggregates exhibit low strength and high porosity, making them unsuitable for direct use in hot mix asphalt surfacing.
2. Blending cinder with basalt significantly improves aggregate strength and durability indices, enabling compliance with AC20 requirements.
3. Blended aggregates containing approximately 30–55% cinder and 45–70% basalt provide the most balanced performance in terms of strength, volumetric properties, and binder demand.
4. Asphalt mixtures incorporating blended cinder aggregates satisfy Marshall stability and volumetric criteria for low-volume roads.
5. Increased binder content associated with cinder aggregates may introduce durability trade-offs (bleeding, rutting, aging) that were not evaluated in this study.
6. The findings should not be generalized to medium or high traffic roads without further performance-based testing.

RECOMMENDATIONS

1. The use of active fillers or additives should be investigated in order to reduce binder demand and further enhancement of performance.
2. Conduct standardized moisture susceptibility testing (e.g., Tensile Strength Ratio – AASHTO T283) to assess stripping resistance.
3. Perform rutting resistance evaluation using wheel tracking or repeated load tests.
4. Investigate long-term aging behavior through short-term and long-term oven aging protocols.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue II February 2026

5. Undertake life-cycle cost analysis to quantify economic benefits.

6. Implement controlled field trials under monitored traffic and environmental exposure conditions.

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