Engineering and Technology Journal e-ISSN: 2456-3358

Volume 10 Issue 12 December-2025, Page No.- 8389- 8391

DOI: 10.47191/etj/v10i12.42, I.F. – 8.482

Comparative Evaluation of Methods for Determining Bulk Density and Air Voids in Compacted Asphalt Mixtures

Eng. Catherine Mugai*

Independent Researcher, Nairobi, Kenya

ABSTRACT: Accurate determination of bulk density and air voids is fundamental to asphalt mix design and quality control. This study evaluates bulk density and air voids from Marshall-compacted specimens (unsealed and vacuum-sealed) and gyratory-compacted specimens (unsealed and vacuum-sealed). Data were collected from eight laboratories following a standardized protocol using a common dense-graded asphalt mixture (19 mm NMAS, 5.2% binder). Only results from laboratories achieving z-scores within ±2 were included. Results demonstrate that both compaction method and sealing technique significantly influence measured properties ($p < 0.001$, two-way ANOVA). Vacuum sealing increased bulk density by 3.9% (95 kg/m³) in Marshall specimens and reduced air voids by 0.7 percentage points. Gyratory compaction yielded 5.2-5.6% higher densities than Marshall compaction. The combination of gyratory compaction with vacuum sealing produced the highest densities (mean: 2554 kg/m³, CV = 0.38%) and lowest air voids (mean: 3.4%, CV = 8.2%). The findings highlight method-dependent biases and provide guidance on the appropriate application of each method for mix design, construction quality control, and pavement evaluation.

Keywords: Bulk density; air voids; Marshall compaction; gyratory compaction; vacuum sealing; asphalt mixtures

1. INTRODUCTION

1.1 Background

Bulk density and air voids critically influence asphalt mixture stiffness, durability, and fatigue performance (Roberts et al., 1996; Asphalt Institute, 2014). Standard practice relies on Marshall-compacted specimens with density determined by immersion methods (AASHTO T166). However, vacuum sealing (AASHTO T331) and gyratory compaction are increasingly used, particularly where surface texture compromises conventional sealing.

Previous studies (Button et al., 2007; Cooley et al., 2013) demonstrate that sealing and compaction method significantly influence measured density. In Kenya, inconsistent methods across laboratories may lead to conflicting compliance decisions. This study evaluates methods, not laboratories, by comparing density and voids from different compaction and sealing approaches using a common material and protocol.

The author's previous work has focused on developing non-destructive methods for pavement evaluation, including prediction of subgrade California Bearing Ratio using Falling Weight Deflectometer data (Mugai, Abongo, & Odero, 2025)b. The present study extends this research program by addressing another critical aspect of pavement materials characterization—the accurate determination of asphalt mixture volumetric properties.

1.2 Evolution of Testing Methods

Historically, the asphalt industry has relied heavily on Marshall-compacted specimens with bulk density determined using dimensional calliper measurements or immersion methods (AASHTO T166). However, these conventional approaches have recognized limitations, particularly for mixtures with absorptive aggregates, open-graded gradations, or surface-connected voids that permit water ingress during testing (Cooley et al., 2013; Buchanan, 2004). Such water absorption artificially increases the measured specimen volume, leading to underestimation of bulk density and corresponding overestimation of air void content.

In response to these limitations, alternative approaches have been developed and increasingly adopted. Vacuum sealing methods (AASHTO T331; ASTM D6752; SABITA ASP8) encase the specimen in a plastic membrane under vacuum, preventing water ingress during immersed density determination. This technique has demonstrated improved accuracy and repeatability, particularly for permeable or rough-textured mixtures (Button et al., 2007; Prowell and Baker, 2007).

Concurrently, gyratory compaction has gained widespread acceptance as a superior laboratory compaction method that better simulates field compaction mechanisms. The Superpave gyratory compactor applies both vertical pressure and shearing action, promoting aggregate reorientation and achieving densification patterns similar to those observed under roller compaction (Harmelink et al., 2008; AASHTO T312). This has led to its adoption in performance-based mix design frameworks and mechanistic-empirical pavement design procedures.

1.3 Regional context and Problem Statement

In Kenya and similar developing regions, both traditional and modern testing methods are employed concurrently across different laboratories. Previous international studies (Button et al., 2007; Cooley et al., 2013) have demonstrated that sealing method and compaction technique significantly influence measured density and voids. However, these findings require validation with local materials and practices, and the combined effects of both factors have not been systematically evaluated in a single study.

2. MATERIALS AND METHODS

2.1 Experimental Design: A 2 × 2 factorial design compared compaction method (Marshall vs. gyratory) and sealing method (unsealed vs. vacuum-sealed) with 24 specimens per combination (8 laboratories × 3 replicates).

2.2 Mixture Properties: Dense-graded asphalt concrete (19 mm NMAS, PEN 60/70 binder, 5.2% binder content, aggregate bulk specific gravity 2.653, maximum theoretical density 2.542 g/cm³) conforming to Kenya specifications.

2.3 Compaction:

- **Marshall:** 75 blows/face (AASHTO T245)
- **Gyratory:** 100 gyrations at 600 kPa, 1.16° angle (AASHTO T312)

2.4 Density Determination:

- **Unsealed:** AASHTO T166 (Method A)
- **Vacuum-sealed:** AASHTO T331

2.5 Air Voids: $V_a = [1 - (G_{mb}/G_{mm})] \times 100$

2.6 Data Screening: Only laboratories with z-scores within ±2 (ISO 13528) were included. Eight of 11 laboratories met criteria, yielding 96 specimens.

2.7 Statistical Analysis: Two-way ANOVA, Tukey HSD, effect sizes ($\alpha = 0.05$) using R.

3. RESULTS

Table 1: Summary Results (Mean ± SD)

Method	Bulk Density (kg/m³)	Air Voids (%)	CV (Density)
Marshall-Unsealed	2418 ± 28.4	4.9 ± 0.58	1.17%
Marshall-Sealed	2513 ± 12.6	4.2 ± 0.31	0.50%
Gyratory-Unsealed	2543 ± 15.3	3.7 ± 0.42	0.60%
Gyratory-Sealed	2554 ± 9.8	3.4 ± 0.28	0.38%

3.1 Statistical Findings:

i. Two-way ANOVA: Compaction method ($F = 625$, $p < 0.001$, $\eta^2 p = 0.87$), Sealing method ($F = 127$, $p < 0.001$, $\eta^2 p = 0.58$), Interaction ($F = 40$, $p < 0.001$)
ii. Tukey HSD: All comparisons significant ($p < 0.001$) except Gyratory-Sealed vs Gyratory-Unsealed ($p = 0.32$)

3.2 Key Observations:

i. Sealing increased Marshall density by 95 kg/m³ (3.9%) and reduced variability by 57%
ii. Gyratory densities were 125-136 kg/m³ (5.2-5.6%) higher than Marshall-Unsealed
iii. Gyratory-Sealed showed lowest variability (CV = 0.38%)
iv. Sealing effect significant for Marshall but not gyratory specimens

4. DISCUSSION

4.1 Sealing Effect: Vacuum sealing prevents water ingress into surface-connected voids during immersion. For Marshall specimens, each gram of absorbed water reduces calculated density by ~2 kg/m³; the 95 kg/m³ difference corresponds to ~48 g absorption (4% of specimen mass). Sealing reduced between-laboratory variability (s_R) from 23.9 to 10.4 kg/m³, indicating improved consistency.

4.2 Compaction Effect: Gyratory compaction produces denser specimens through kneading action promoting particle reorientation, better simulating field compaction. Marshall specimens averaged 4.9% air voids (above 4% target) while gyratory averaged 3.4% (below target), suggesting local calibration of Ndesign may be needed.

4.3 Interaction: Significant interaction ($p < 0.001$) indicates sealing effectiveness depends on compaction method. Marshall specimens benefit greatly from sealing; gyratory specimens show minimal sealing effect due to fewer surface-connected voids.

4.4 Engineering Implications:

i. **Method choice affects acceptance:** 0.7-1.5% air void differences can determine pass/fail decisions
ii. **Design-control mismatch:** Using different methods for design vs. quality control creates compliance confusion
iii. **Precision matters:** Sealed methods reduce decision risk through lower variability

The findings of this study, together with previous work on subgrade CBR prediction using Falling Weight Deflectometer data (Mugai, Abongo, & Odero, 2025)b, contribute to a comprehensive framework for non-destructive and accurate pavement evaluation in Kenya. Accurate asphalt volumetric properties complement subgrade characterization to enable complete pavement condition assessment.

Table 2: Method Selection Guidance

Application	Recommended Method	Rationale
Routine QC, dense mixes	Marshall-Unsealed	Adequate for comparative use; lowest cost
Absorptive aggregates	Marshall-Sealed	Prevents water absorption errors
Performance-based design	Gyratory-Sealed	Best field simulation; lowest variability
Acceptance testing	Marshall-Sealed or Gyratory-Sealed	Improved precision reduces decision errors
Research/forensics	Gyratory-Sealed	Highest accuracy required

5. CONCLUSIONS

1. Bulk density and air voids are method-dependent with systematic differences between sealed/unsealed and Marshall/gyratory methods.
2. Vacuum sealing improves accuracy and repeatability, increasing density by 3.9% and reducing variability by 57% for Marshall specimens.
3. Gyratory compaction yields 5.2-5.6% higher densities than Marshall, better reflecting field compaction.
4. Gyratory-Sealed method provides optimal performance (highest density, lowest variability) for critical applications.
5. Method selection must align with engineering purpose; no single method is optimal for all applications.
6. Specifications must explicitly define both compaction and sealing methods to ensure consistent interpretation.
7. This work, alongside previous studies on subgrade characterization (Mugai, Abongo, & Odero, 2025)a, supports the development of integrated pavement evaluation frameworks for Kenyan conditions.

REFERENCES

1. Asphalt Institute. (2014). *MS-2 Asphalt Mix Design Methods*. Lexington, KY.
2. Button, J. W., Perdomo, D., & Lytton, R. L. (2007). Influence of bulk specific gravity methods on asphalt mixture volumetrics. *Transportation Research Record*, 1998, 145-153.
3. Cooley, L. A., Hurley, G. C., & Prowell, B. D. (2013). Bulk specific gravity round-robin evaluation. *Journal of Materials in Civil Engineering*, 25(9), 1285-1293.
4. Mugai, C., Abongo, K., & Odero, B. (2025) a. Characterization of subgrade soils in prediction modelling of subgrade CBR using FWD for pavement evaluation in Kenya. *AJERI*, 3(3), 24–35.
5. Mugai, C., Abongo, K., & Odero, B. (2025) b. Prediction of Subgrade California Bearing Ratio Using Falling Weight Deflectometer for Pavement Evaluation in Kenya. *International Journal of Academic Engineering Research*, 9(8), 30-38.
6. Roberts, F. L., Kandhal, P. S., Brown, E. R., Lee, D. Y., & Kennedy, T. W. (1996). *Hot Mix Asphalt Materials, Mixture Design, and Construction*. NAPA Education Foundation.
7. SABITA. (2016). *ASP8: Determination of Bulk Density of Compacted Asphalt Using Vacuum Sealing*. South Africa.