International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

https://gssrr.org/index.php/JournalOfBasicAndApplied/index

---

# Design of Hot Marshall Asphalt Concrete Mixes by Using Cinder Aggregates for Construction of Sealed Layer of Low Volume Roads in Mbeya Tanzania

Ally Seleman Mwita[a]*, Dr. Duwa Hamisi Chengula[b], Prof. Joseph John Msambichaka[c]

*[a,b,c]Mbeya University of Science and Technology, College of Engineering and Technology, Department of Civil Engineering, P.O. Box 131 Mbeya, Tanzania*

*[a]Email: mwitachacha45@gmail.com*

*[b]Email: chengula@yahoo.com*

*[c]Email: jjmsambichaka@yahoo.com*

**Abstract**

The availability of high quality aggregates for production of hot Marshall Asphalt (HMA) mixes for construction of sealed surfacing layer that meet specified standards are becoming scarce. The use of locally available marginal materials shows challenges of not meeting engineering properties for construction of surfacing layers of Low Volume Roads (LVRs). This study investigated stability, flow and volumetric properties of the blended marginal natural cinder aggregates and sand to produce HMA mixes for construction of sealed surfacing layers of low volume roads and 60/70 asphalt was used as binder to aggregates. The 60/70 asphalt binder was sourced from local supplier in Dar es Salaam, natural cinder was sourced from Ituha area and sand materials were sourced from Mbalizi area in Mbeya Region. Physical properties of 60/70 asphalt materials, physical and mechanical properties of natural cinder aggregates and sand were determined under laboratory condition.

---

*Received: 2/3/2025*
*Accepted: 4/10/2025*
*Published: 4/21/2025*

---

* Corresponding author.

The tests performed for 60/70 asphalt binder includes; ductility, penetration, flash point, viscosity and softening point. The test results from characterization of 60/70 asphalt binder indicated that all properties met the requirement to be used for HMA mixes for construction of sealed surfacing layer of low volume roads. The mechanical properties tests performed for natural cinder aggregates and sand includes TFV and ACV. The test results indicated that only sand satisfied requirement for TFV. Blending process of natural cinder aggregates and sand was conducted in order to meet gradation specification of AC20. The results of TFV and ACV for blended aggregates satisfied requirements for HMA mixes for construction of sealed surfacing layers of low volume roads in Mbeya Region Tanzania.

The results of volumetric properties, flow and stability test conducted for HMA mixes are 9.2% optimum asphalt content, 5.5% air voids, 21.6% VMA, 13kN stability and 3 mm flow. It is indicating that optimum asphalt content, void properties, stability and flow met the requirement as HMA materials for the construction of surfacing layers of LVRs in Mbeya Region Tanzania, although the optimum asphalt content is at higher side due to high porosity of cinder aggregate materials. From the results of this study, it is recommended that cinder aggregate materials should be blended with high quality aggregates in order to increase mechanical properties of cinder blended aggregates for hot mix asphalt concretes. It is also recommended that filler materials to be used in order to reduce porosity of cinder aggregate materials which will reduce amount of asphalt contents for HMA mixes.

***Keywords:*** Low volume roads; cinder aggregates; blended process; characterization; asphalt concrete; stability; flow; density; mix design; HMA; volumetric analysis.

## 1. Introduction

Low volume roads (LVRs) are the roads which are designed and constructed to serve 50 – 400 vehicles a day with pavement layers and materials capable to resist vehicle axle loads up to 1.0 million CESAL (cumulative equivalent standard axle loads) during its design life [1, 2, 3]. In Tanzania the LVRs comprise of 75% of the whole road network [1, 3] and these LVRs play major role of transporting goods, people and agricultural inputs from urban market to rural areas. In Tanzania about 80% of population lives in rural areas where the major economic activities conducted is agriculture [4]. Currently the function ability of LVRs in Tanzania seems difficult due to high maintenance cost caused by scarcity of suitable conventional natural aggregate in some areas of the country especially regions where the great rift valley has passed through [1].

Cinder aggregates can be used as alternative aggregates since they are abundantly available in many areas especially where the Great Rift Valley belt zone have passed through which includes Central area of Tanzania, Mbeya, Songwe, Arusha, Rukwa and Kilimanjaro Regions [5]. These Regions have scarcity of strong and durable rocks to be used for production of conventional aggregates. The abundant available materials are pumices, cinder aggregates, volcanic cinder rocks and stones which can be crashed into aggregates [5].

These materials have been categorized as marginal materials because they lack some engineering properties to be used for road construction [1, 6]. Cinders aggregates are natural aggregates which are formed due to volcanic action having lower quality standard of physical and mechanical properties for construction of LVRs. They have high void contents that absorbs high amount of water, low specific gravity and relatively soft particles [7]. These shortfalls have resulted into a low or improper usage of volcanic materials in Tanzania [8]. In Africa cinder materials have been reported to be abundant available in Ethiopia, Kenya, Uganda, Tanzania, Rwanda, Burundi, Congo and Malawi [9].

Despite of the abundance availability of natural cinder aggregates in many areas in Tanzania but they are less recommended for construction of pavement layers due to limited specified engineering properties [10, 11, 12]

The past research on experimental use of cinder gravel and aggregate on roads in Ethiopia for unpaved and paved (surface dressing) showed that cinder could be used for sub-base, base course, surface dressing and not for asphalt concrete layer due to high absorption of binder content and low strength of aggregate particles [13, 14, 15]. It is investigated that when cinder gravel blended with volcanic ash or quarry fines can be used for sealed road with up to 0.44 million CESALs for construction of sealed surface dressing which is to be designed according to overseas road note 31 [16, 17]. According to ERA [18] indicated that cinder gravel was used for constructing bituminous surfacing layer in trial section at Combel Village on Tolubolo in Ethiopia and the trial section performed well. However, the trial section required high bitumen spray rate because of high absorption capacity of cinder materials. Therefore, natural cinder aggregate needs to be improved in both physical and strength properties so as to be used in construction of asphalt concrete roads.

Since the availability of high quality conventional aggregates for HMA mixes that meet specified standards are becoming scarce the studies have risen a need to investigate cinder aggregates as alternative aggregates for design and construction of asphalt concrete road surfacing layer for low volume roads [18, 3, 16, 18].

In Tanzania standard conventional aggregate used for asphalt concrete mixtures are obtained from crushed granite, igneous and basaltic rocks. In many areas of the world strong and durable aggregate has been inadequate or depleted, due to construction activities which requires tones of superior materials and mining activities [6, 11, 13]. Resulting into looking alternative aggregate which can be sourced locally and improved in both physical and mechanical properties and to be used for mix design and construction of asphalt concrete surfacing layer for low volume roads [19].

Despite the abundance availability of natural cinder aggregate in many areas of Tanzania, they have challenges of lacking some specified engineering properties required for design and construction of road sealed asphalt pavement surfacing layer which are low strength of particles that may result into crushing and failure of pavement, high water absorption that may result in loss of strength and durability and high porosity rate that may results into high demand of asphalt binder when used for asphalt wearing course [13, 6]. However, this study has investigated, stability, flow and volumetric properties of Hot Marshall Asphalt (HMA) concrete mixes made from natural cinder aggregate blended with sand materials for construction of sealed pavement layers of low volume roads in Mbeya Region Tanzania.

## 2. Investigation Procedure and Approach

### *2.1. Materials Collection*

The materials used in this study were cinder aggregate, sand and 60/70 bitumen. Cinder aggregates were sourced from Ituha and sand were obtained from Mbarizi river in Mbeya City while 60/70 pen grade bitumen was obtained from local suppliers in Dar es salaam Tanzania.

### *2.2. Methodology*

The source materials used for this study which are cinder, sand and 60/70 pen grade bitumen were laboratory characterized to determine their physical and mechanical properties before blending and testing for hot Marshall Mixes. The tests conducted for sample aggregate materials are sieve size analysis, specific density (SG), water absorption (WA), ten percent fine value (TFV), aggregates crushing value (ACV), aggregates impact value (AIV), flakiness index (FI) and elongation index (EI). The tests conducted for sample sand materials are sieve size analysis, specific density (SG) and water absorption (WA). The laboratory tests conducted on 60/70 pen grade bitumen are flash point, viscosity, ductility, specific gravity, softening and penetration which are important properties of virgin bitumen for hot mix asphalt mixes. However, materials blending design and Marshall Mix design for hot mix asphalt concretes were conducted. The asphalt concrete specimens were tested to determine their stability, flow and volumetric properties. Physical, strength and volumetric properties were determined following the procedures stipulated in MoW 2000a and MoW 2000b [10, 20].

### *2.3. Characterization of Cinder aggregates and Sand Materials*

The cinder aggregates and sand materials were washed to remove dusts and organic materials. Wet sieve analysis was conducted following the procedures stipulated in MoW 2000a [20] to determine particle size distribution. Figure 1 shows particle size distribution curves of sand and cinder aggregates.

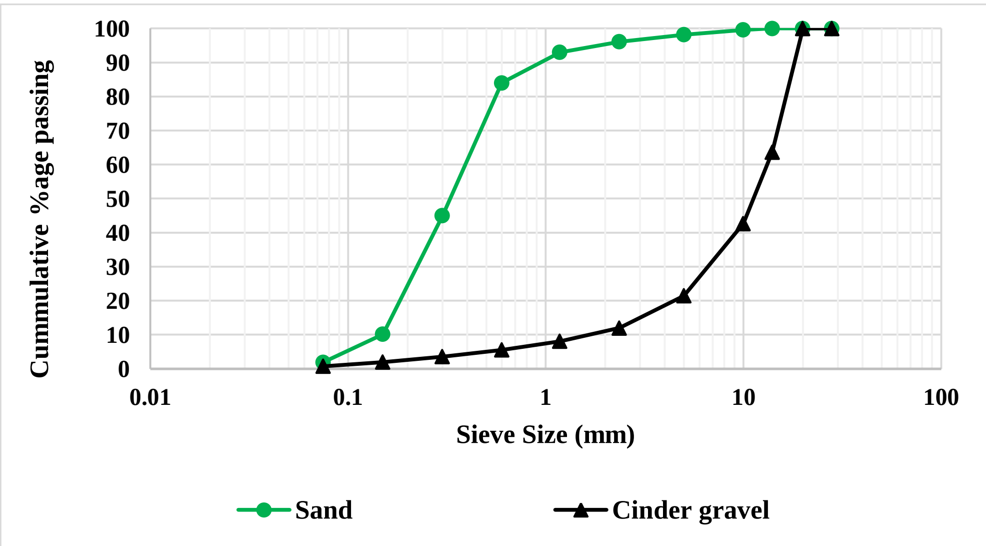


**Figure 1:** Gradation curves of sand and cinder aggregates

The test results for physical and mechanical properties of cinder aggregates and sand indicates that TFV, ACV and AIV for Cinder aggregates did not meet the required engineering properties for construction of sealed surfacing layer of low volume roads [10]. However, river sand satisfied TFV requirements except for ACV which is slightly higher than 25% specified [10]. For low volume roads these specification values are at higher side, this is because LVRs carries maximum axial load of 1 million cumulative equivalent standard axle loads (CESAL) and number of vehicles less than 400 veh/day [3]. However other studies have specified values for ACV to be 28 to 30%, [21, 22] AIV to be 10 to 30% [23] and minimum TFV to be 110kN [24]. The blending process of cinder aggregates and sand for Marshall Mix design were also conducted. Table 1 shows physical and mechanical properties of cinder aggregates and sand used for this study.

**Table 1:** Physical and mechanical properties of Cinder aggregates and sand

| **Source materials** | **Material properties** | | | | | | |
|---|---|---|---|---|---|---|---|
| | SG | WA | TFV | ACV | AIV | EI | FI |
| Cinder aggregates | 2.45 | 2.63 | 100 | 30.7 | 25.2 | 5.46 | 4.56 |
| Sand | 2.35 | 1.92 | 146 | 26.6 | N/A | N/A | N/A |
| Specification limit [2] | N/A | N/A | 130 min (dry) | 25 max | 25 max | 25 max | |

### *2.4. Blending Design of Aggregates and Sand*

The cinder aggregates and sand were blended together in order to obtain gradation which lays within the envelope of AC20 for Marshall mixes as specified in MoW 2000b [10]. The blending processes were conducted following procedures and formulas stipulated by Chengula [25]. Equations 1, 2 and 3 are used to compute grading factors (GF), median particle sizes (MS) and proportions of cinder aggregates and sand.

$$GF = \frac{\sum_{P=0}^{100} PP_i * SS_i}{\sum_{P=0}^{100} PP_i} \quad (1)$$

$$MS = \frac{\sum_{i=0}^{n} PR_i * SS_i}{100} \quad (2)$$

$$PA = \frac{(GF_U + GF_L - 2GF_B) + (MS_U + MS_L - 2MS_B)}{2[(GF_A + MS_A) - (GF_B + MS_B)]} \text{ and } PB = 1 - PA \quad (3)$$

**Where:** “PPi” – denotes percentage passing sieve size in mm, “PRi” – denotes percentage retained on sieve size in mm; “SSi” – denotes sieve size for each percentage retained. $GF_A$ and $GF_B$ - are gradation factors of aggregate A and B respectively, $MS_A$ and $MS_B$ are the median particle sizes of aggregate A and B respectively. $MS_L$ and $MS_U$ are the median particle sizes of lower and upper gradation envelopes respectively, $GF_L$ and $GF_U$ – are the gradation factors of lower and upper gradation envelopes respectively. PA and PB – are proportions of aggregate type A and B in decimals respectively.

Table 2 gives grading factors and median particle sizes for cinder aggregates, sand, upper limit and lower limit of gradation envelope for AC20 asphalt mixes. The average proportions of cinder aggregates and sand obtained after blending process are 75% for cinder and 25% for sand (25Sa75Ci). The mixture of sand and cinder aggregates were then used for hot mix asphalt concrete mixes.

**Table 2:** Grading factor and median particles sizes of materials and gradation envelope

| Parameters | | Cinder | Sand | Lower limit (LL) | Upper limit (UL) |
|---|---|---|---|---|---|
| GF | Min | 5.2 | 13.4 | 14.8 | 9.8 |
| | Max | 9.8 | 17.4 | 14.8 | 12.9 |
| MS | | 0.4 | 8.5 | 8.8 | 5.0 |

Figure 2 indicates gradation curve of blended cinder aggregates and sand materials at proportion of 25% sand and 75% cinder aggregates laying within the aggregates envelope of AC20 asphalt concrete [10].

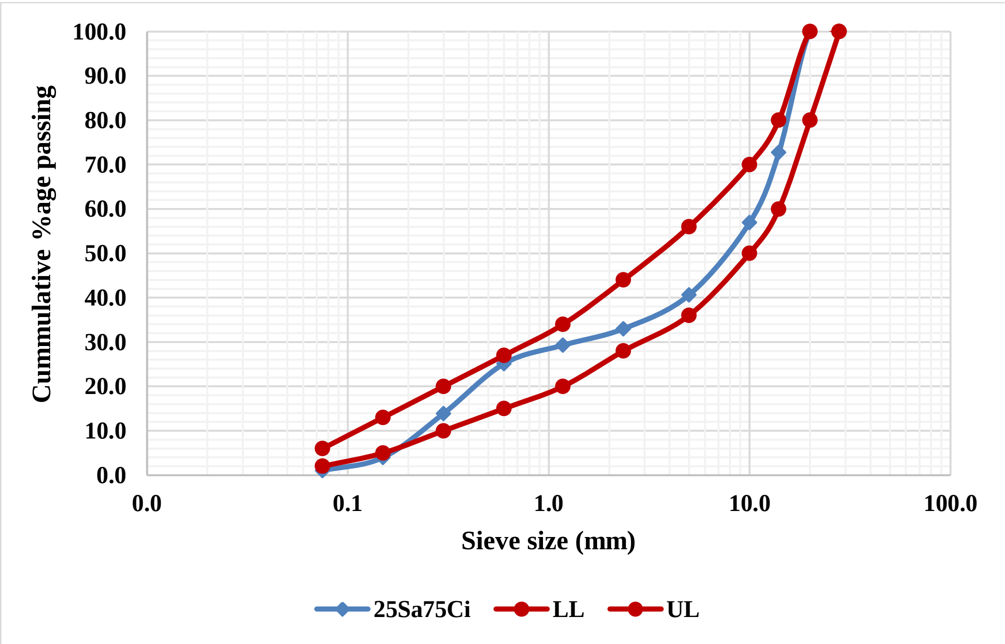


**Figure 2:** Blended cinder and sand (25Sa75Ci) in AC20 envelope

### *2.5. Properties of Virgin 60/70 Asphalt for Marshall Mixes*

The Marshall method does not have generic asphalt binder selection and evaluation procedure. Each design entity uses their own method with modifications to determine the appropriate binder type and if any, modifiers. Binder selection and evaluation can be based on climate condition, road classes, local experience and previous performance or a set procedure and several bitumen tests should be done to determine quality characteristics of the selected asphalt binder [26. 27]. The 60/70 pen grade bitumen were obtained from local suppliers in Dar es salaam and the tests to determine properties of virgin 60/70 pen grade bitumen were conducted in TANROAD laboratory located in Mbeya City . The 60/70 bitumen used in this study was selected based on climatic condition of Mbeya region. The tests conducted on sample bitumen are flash point, viscosity, ductility, specific gravity, softening point and penetration. The tests were conducted following the procedures stipulated in [20, 28, 30]. Table 3 shows laboratory test results for physical properties of 60/70 pen grade asphalt used for this study.

**Table 3:** Properties of 60/70 pen grade bitumen

| **Parameter** | **Ductility test** | **Viscosity** | **Flash point** | **Penetration** | **Density** | **Softening point** |
|---|---|---|---|---|---|---|
| **Results** | 135 cm | 0.333 Pa.s | 310 °C | 67.4 1/10mm | 1027 Kg/m$^3$ | 54.6°C |
| **Criteria** | 100 min | 3.0 max | 230 min | 60 – 70 | 1010 – 1060 | 49 – 56 $^0$C |

### *2.6. Hot Marshall Asphalt (HMA) Concrete Mix Design*

Marshall Asphalt mix method was used in designing, evaluating and selecting the asphalt binder content at a desired density–voids analysis that satisfies stability and flow tests values [8, 20, 26]. The Marshall's flow and stability of the hot Marshall asphalt (HMA) specimens were conducted following the procedure stipulated in MoW 2000a and ASTM-D6927 [20, 29], which are defined as the maximum deformation and maximum load carried by a compacted specimen at a standard test temperature of 60$^0$C.

#### *2.6.1 Marshall Mix Design Procedure*

To perform the Marshall mix design method, the following procedures were used; selection of asphalt binder suitable for the prevailing climate, selection of aggregates, creation of an aggregate blend that meet the gradation criteria, establishing specimen mixing and compaction temperature from viscosity-temperature chart for the hot asphalt concrete mix design, compaction of three specimens at each of five asphalt contents spanning the expected optimum asphalt content, calculation of density and voids (Gmb, Gmm, VTM, VMA, VFA) of each specimen and determining stabilities and flows at each asphalt content.

#### *2.6.2 Sample Preparation*

The Marshall method, similar to other design methods, the sample preparation was performed using several trials of aggregate - asphalt binder contents, normally 5 different asphalt contents with 3 replicates specimens for each asphalt content making total of 15 specimens. In order to estimate amount of bitumen for each point, optimum bitumen content of HMA was estimated.

#### *2.6.3 Optimum Asphalt Binder Content Estimation*

In determining the optimum binder content of blended cinder aggregates the Marshall method was used, and a series of test specimens were prepared for a range of different asphalt contents. For this study, the asphalt content used for HMA mixes increased from 6.4% to 11.6% at an interval of 1.3%. The optimum asphalt content was estimated by using equation 4 [30].

$$P_T = 20.7\log(VMA) - 15G_{sb} + 21.6 \qquad 4$$

**Where:** $P_T$ - Optimum asphalt content, VMA - Voids in mineral aggregate of HMA, Gsb - Bulk specific gravity of blended aggregate

The minimum VMA for AC20 is 14% [10] and bulk specific gravity of blended cinder aggregates and sand materials determined from this study is 2.425g/cm$^3$, therefore substitute value of VMA and Gsb in equation 4 the optimum asphalt content was calculated to be 9%.

### *2.7. Mixing Process of Marshall Specimens*

The mixing process of Marshall Specimens involved blending cinder aggregates and sand together at the determined proportion of 75% cinder aggregates and 25% sand materials in order to meet desired gradation specification.

The mixture of cinder aggregates, sand and asphalt for each asphalt content were mixed in mechanical mixer at a mixing temperature of 160$^0$C until all aggregates and sand mixtures were coated with asphalt. The mixture for each binder content were compacted for 75 blows on both side using Marshall Compactor to simulate field condition into cylindrical moulds of 102 mm diameter by 64 mm height were removed from the moulds by using extrusion jack. Figure 3 shows mixing machine used to mix mixture of heated asphalt binder and aggregates and loose hot asphalt concrete mixes. Therefore, after determining stability and flow of hot asphalt concrete specimens, the densities and voids analysis of asphalt mixes for each binder content were determined to check if the density and volumetric properties were within the allowable range.


**Figure 3:** Asphalt concrete mixing machine (A) and loose asphalt concrete mixes (B)

### *2.7.1 Bulk Specific Gravity of aggregates (Gsb)*

The bulk specific density of aggregates is the ration of the given weight of the given volume of aggregate to the weight of an equal volume of water including permeable and impermeable voids within the aggregate, it is determined using the procedure stipulated in MoW 2000a [20]. Equation 5 is used to compute bulk specific density of aggregates ($G_{sb}$) [20]. It is an important parameter because it is used to compute the amount of asphalt binder absorbed by the aggregate void mineral aggregate (VMA) of the Hot Mix Asphalt (HMA) mixture.

$$\mathrm{Gsb} = \frac{A}{(B+D-C)} \quad (5)$$

**Where:** $G_{sb}$ – is the bulk specific gravity of aggregates (g/cm$^3$), A – is the weight of oven dried sample in air (g), B – is the weight of saturated surface dry aggregate sample in air (g), C – is the weight of pycnometer filled with sample in water (g), D – is the weight of pycnometer filled with water (g).

### *2.7.2 Bulk Specific Gravity of the Asphalt Mix ($G_{mb}$)*

The bulk specific gravity of the asphalt mix is density of compacted asphalt mixture as measured in the laboratory, it is determined using the procedure stipulated in MoW 2000a [20]. Equation 6 is used to compute theoretical maximum density (Gmb) of compacted mix of asphalt concrete. It is an important parameter because it is used to determine the optimum asphalt content of asphalt mix.

$$Gmb = \frac{A}{(A-B)} \quad (6)$$

**Where:** $G_{mb}$ – is the bulk specific density of specimens (g/cm$^3$), A – is the weight of specimen in air (g), B – is the weight of specimen in water (g).

### *2.7.3 Theoretical Maximum Specific Gravities ($G_{mm}$) of Loose Mix*

Theoretical maximum density of loose mix of asphalt concrete is a density of aggregates coated with bitumen at zero entrapped air content. The sample is weighed in air, then placed in vacuum desiccator to remove entrapped air bubbles and then weighed in water, following the procedure stipulated in MoW 2000a [20]. Equation 7 is used to compute theoretical maximum density ($G_{mm}$) of loose mix of asphalt concrete [20]. $G_{mm}$ plays a critical volumetric mix parameter for allocating the optimum asphalt content and it is used to compute air void of the specimens of asphalt mixture. Figure 4 is photo of vacuum desiccator and loose samples of asphalt mixes for testing $G_{mm}$.

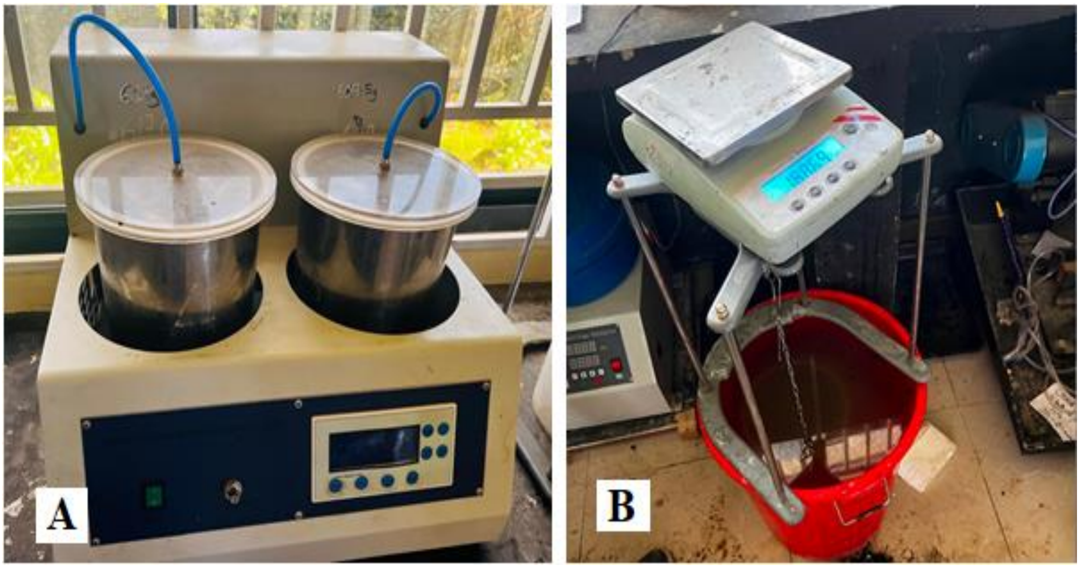


**Figure 4:** Vacuum desiccator (A) and measuring weights of loose Asphalt mix in water (B)

$$G_{mm} = \frac{A}{A-(C-B)} \tag{7}$$

**Where:** $G_{mm}$ – is the theoretical maximum specific gravity of paving mixture, A – is the weight of sample in air (gm), B – is the weight of sample and container in water (gm) and C – is the weight of container in water.

### *2.7.4 Air Voids of Asphalt Aix (VA)*

Air voids of asphalt concrete are the small pockets of air between the aggregate particles in asphalt concrete mixture. It is determined using the procedure stipulated in MoW 2000a [20]. Equation 8 is used to compute air voids of asphalt mix (VA) of compacted mix of asphalt concrete [20]. It is an important parameter because it is used to compute air void of the specimens

$$VA = \left(1 - \frac{G_{mb}}{G_{mm}}\right) 100 \tag{8}$$

**Where**: VA – is air voids of asphalt mix in percentage, $G_{mb}$ – is bulk specific density of asphalt concrete, $G_{mm}$ – is theoretical maximum specific density of loose mix

### *2.7.5 Voids in Mineral Aggregates (VMA)*

Voids in mineral aggregate (VMA) refers to empty spaces between individual aggregate particles within a compacted asphalt mixture. It is determined using the procedure stipulated in MoW 2000a [20]. Equation 9 is used to compute voids in mineral aggregates (VMA) of compacted mix of asphalt concrete [20]. It is an important parameter because it is used to compute air void of the specimens

$$\text{VMA} = 100 - \frac{(100-\text{P}_\text{b})G_{mb}}{\text{G}_\text{sb}} \qquad 9$$

**Where:** VMA – is the voids in mineral aggregate in %, Gsb – is the bulk specific gravity of aggregate, Gmb – is bulk specific gravity of compacted mixture, Pb – is the binder content in percentage

### *2.7.6 Voids Filled with Asphalt (VFA)*

Voids filled with asphalt (VFA), refers to the percentage of voids in the compacted aggregate mass that are filled with asphalt binder. It is determined using the procedure stipulated in MoW 2000a [20]. Equation 10 is used to compute Voids filled with asphalt (VFA) of compacted mix of asphalt concrete [20]. It is an important parameter because it is used in predicting hot mix asphalt pavement performance.

$$\text{VFA} = \left(\frac{\text{VMA}-VA}{\text{VMA}}\right)100 \qquad 10$$

**Where:** VFA – is the voids filled with asphalt (%), VMA – is the voids in mineral aggregate (%), VA – is the air voids (%)

### *2.7.7 Marshall Stability and Flow Tests*

After mixing and compaction process, the Marshall specimens were ready for testing, typically involved measuring their stability (resistance to shear) and flow (deformation under load) using a Marshall stability testing machine to determine the optimum asphalt binder content for the Hot Mix Asphalt concrete design. Figure 5 shows Marshall Stability and flow machine used for this study.


**Figure 5:** Stability and flow machine (A) and Asphalt concrete specimens (B)

## 3. Results and Discussion

The analysis of Laboratory tested sample materials was based mainly on the parameters required for the selection of materials to be used for the construction of surfacing layers of bound low volume roads (LVRs) which are grading envelopes, ten percent fines values (TFV), Specific gravity (SG) and Water absorption(WA)

**Table 4:** Physical and mechanical properties of cinder blended sand materials (25Sa75Ci)

| **Blended materials** | **SG** | **WA** | **TFV** | **ACV** | **AIV** | **EI** | **FI** |
|---|---|---|---|---|---|---|---|
| **25Sa75Ci** | 2.43 | 2.45 | 112 | 29.6 | N/A | N/A | N/A |

The results of mechanical properties of cinder blended sand aggregates are shown in table 4. It has been indicated that there are improvement of TFV value and ACV value of cinder after blending with sand at a blending proportion of 75% cinder aggregates and 25% sands. Table 5 shows the theoretical maximum density of loose mix for each binder content used for HMA mixes for this study.

**Table 5:** Test data of theoretical maximum density ($G_{mm}$) of loose mix of Marshall Specimens

| **Test points** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Asphalt contents** | 6.4% | 7.7% | 9.0% | 10.3% | 11.6% |
| **Theoretical maximum density ($G_{mm}$)** | 2.29 | 2.25 | 2.20 | 2.23 | 2.14 |

The specification for volumetric properties, flow and stability of hot mix asphalt concrete for construction of surfacing layers of road pavements are indicated in MoW 2000b [10]. Table 6 gives the optimum values of asphalt content, densities, volumetric properties, stability and flow of the hot asphalt concrete mixes for cinder aggregates. The results in table 6 indicate that the volumetric properties, flow and stability of hot mix asphalt concrete met the required specification, except the asphalt content which is higher compared to that specified for conventional aggregate mixtures which ranges between 4 to 6% [10]. This is because cinder aggregates are porous materials to which its absorption rate is much higher compared to conventional aggregates which demands higher amount of asphalts for mixing [26]. Figure 6 shows the curves showing relationships between densities, volumetric properties and asphalt contents.

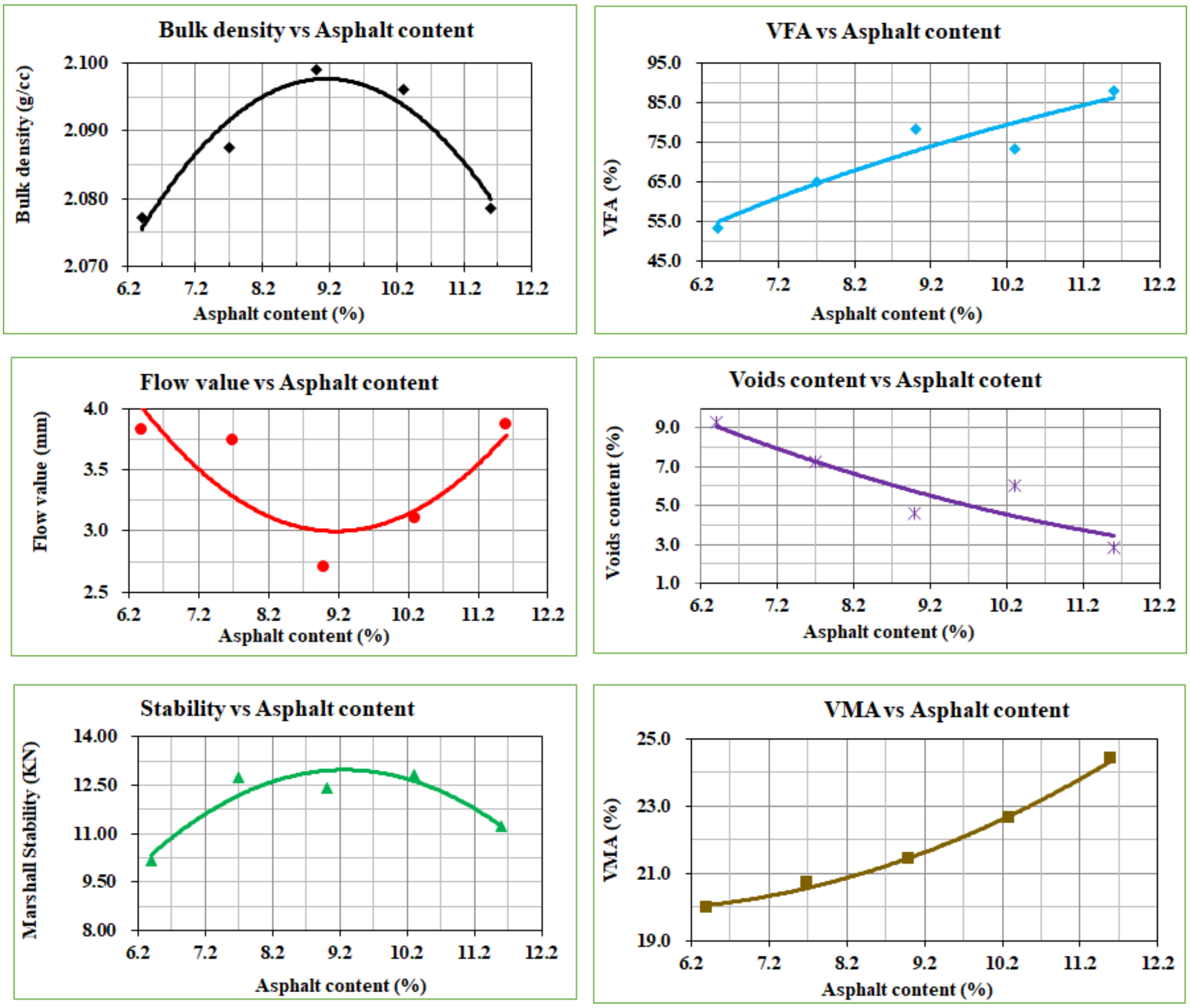


**Figure 6:** Laboratory Marshall volumetric, flow and stability chart of 25Sa75Ci specimens

However, according to Speight [22] indicated that in the hot asphalt mix, the aggregate constitutes 90 to 95% of the total mixture and asphalt binder constitutes between 5 to 10% of the total mixture to form asphalt concrete. The Asphalt institute indicated that, typical asphalt content for HMA ranges between 4 to 7% by weight, but at higher end the asphalt content ranges between 7 to 10% which is due to use of lower quality aggregates, aggregate gradation or cold climates [31]. AASHTO M23 indicated that, typical asphalt content for HMA ranges between 4 to 6% for good quality aggregates but it can go up to 9 to 10% for HMA requiring higher durability and stability [32]. Therefore, marginal materials like cinder aggregates requires higher asphalt content for making HMA.

**Table 6:** Test data of theoretical maximum density (Gmm) of loose mix of Marshall Specimens

| **Parameters** | **Optimum bitumen** | **Gmb** | **Gsb** | **Air Voids** | **VMA** | **VFA** | **Stability** | **Flow** |
|---|---|---|---|---|---|---|---|---|
| **Unity** | % | g/cc | g/cc | % | % | % | kN | mm |
| **Value** | 9.2 | 2.098 | 2.43 | 5.5 | 21.6 | 75 | 13 | 3 |
| **Limiting values [2]** | N/A | N/A | N/A | 3 - 6 | 14 min | 65-75 | 9 min | 2 - 4 |

In this regard, the optimum binder content of 9.2% by weight of the mix, air voids of 5.5%, VFA of 75% and VMA of 21.6% indicted in table 6 are acceptable for HMA made by using marginal cinder aggregates for surfacing layer of low volume roads construction in Tanzania [3, 21, 22].

## Conclusions and Recommendations

### *3.1 Conclusions*

The study carried out to design HMA for construction of low volume roads in Mbeya Tanzania based on marginal natural cinder aggregates blended with river sand. Characterization of source materials that are asphalt, cinder aggregates and sand were conducted under laboratory condition.

The results of the properties of 60/70 Asphalt binder indicated that the ductility, penetration, viscosity, flash point and softening point obtained from laboratory tests are 135cm, 67.4 (1/10 mm), 0.333Pa.s, $310^0$C and $54.6^0$C respectively which are within the requirements for HMA mixes. The mechanical properties of cinder aggregates indicated that TFV values are 100kN and 146kN and for ACV are 30.7% and 26.6% for cinder aggregates and sand respectively. The cinder aggregates did not satisfy the mechanical properties and sand aggregate satisfied TFV requirements. The cinder aggregates were blended with sand into proportion of 75% cinder and 25% sand by weight in order the gradation of blended material lay within the recommended gradation envelopes for AC20. The TFV and ACV of the blended aggregates are 112kN and 29.6%.

The mix design of HMA were done and results of optimum binder content, volumetric properties, stability and flow for this are 9.2% optimum asphalt content, 5.5% air voids, 21.6% VMA, 13kN stability and 3 mm flow. The results indicate that optimum binder content; all volumetric properties, stability and flow met the requirement as HMA materials for the construction of surfacing layers of LVRs in Tanzania.

### *3.2 Recommendations*

Since the research was based on the laboratory tests of natural cinder aggregate and blended cinder aggregate at a controlled condition, therefore there is a need to validate the findings in the field where the cinder aggregate materials are to be used for road construction. However, cinder aggregate materials can be blended with granite and basalt aggregate materials in order to increase mechanical properties of cinder blended aggregates for hot mix asphalt concretes. It is also recommended that filler materials to be used in order to reduce porosity of cinder aggregate materials that will reduce amount of asphalt contents for HMA.

## 4. Appendix

**Table 1A:** Laboratory Marshall design data for HMA specimens

| Type of Asphalt concrete is AC20 | | | | | | | | | Absorbed Asphalt (%): 1.07 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bulk SG of aggregate is 2.430 | | | | Specific Gravity of Bitumen is 1.03 | | | | | Compaction: 75 Blows top and bottom | | | | |
| Spec. No. | % Asphalt by wt. of mix | Specimen Height (mm) | Wt. of Specimen in air (g) | Wt. of Specimen in water (ssd) (g) | Bulk Volume ($cm^3$) | Bulk SG of specimen ($g/cm^3$) | Max SG (Loose Mix) | % Air Voids | % VMA | % VFA | Stability (N) | Corrected Stability (kN) | Flow, in 0.025mm |
| 1 | 6.4 | 63.0 | 982.6 | 512.4 | | | | | | | 12600.0 | | 4.53 |
| 2 | | 64.0 | 977.1 | 503.9 | | | | | | | 7100.0 | | 3.12 |
| **Av.** | | **63.5** | **979.9** | **508.2** | **471.7** | **2.077** | **2.29** | **9.3** | **20.0** | **53.5** | **9.9** | **10.2** | **3.8** |
| 1 | 7.7 | 62.8 | 944.7 | 488.5 | | | | | | | 11000.0 | | 4.0 |
| 2 | | 60.0 | 971.4 | 509.7 | | | | | | | 13680.0 | | 3.4 |
| Av. | | **61.4** | **958.1** | **499.1** | **459.0** | **2.087** | **2.25** | **7.2** | **20.7** | **65.1** | **12.3** | **12.7** | **3.7** |
| 1 | 9 | 62.0 | 978.1 | 509.8 | | | | | | | 11500.0 | | 2.7 |
| 2 | | 62.0 | 987.1 | 519.1 | | | | | | | 12540.0 | | 2.7 |
| Av. | | **62.0** | **982.6** | **514.5** | **468.2** | **2.099** | **2.20** | **4.6** | **21.4** | **78.5** | **12.0** | **12.4** | **2.7** |
| 1 | 10.3 | 57.0 | 978.3 | 516.1 | | | | | | | 12480.0 | | 3.0 |
| 2 | | 64.0 | 980.4 | 508.1 | | | | | | | 12380.0 | | 3.2 |
| Av. | | **60.5** | **979.4** | **512.1** | **467.3** | **2.096** | **2.23** | **6.0** | **22.6** | **73.4** | **12.4** | **12.8** | **3.1** |
| 1 | 11.6 | 57.0 | 965.9 | 502.8 | | | | | | | 11800.0 | | 3.0 |
| 2 | | 62.0 | 961.6 | 497.4 | | | | | | | 9960.0 | | 4.8 |
| Av. | | **59.5** | **963.8** | **500.1** | **463.7** | **2.079** | **2.14** | **2.9** | **24.4** | **88.2** | **10.9** | **11.2** | **3.9** |


**Figure A1:** Photo for source Cinder materials (A) and Sand materials (B)


**Figure A2:** Photo for Marshall compaction process (A) and specimens (B)

**References**

[1] D. Hamisi Chengula and J. Kilango Mnkeni, "Improving Properties of Cinder Blended Materials for Construction of Low Volume Roads in Mbeya Region Tanzania," American Journal of Construction and Building Materials, vol. 5, no. 1, p. 22, 2021, doi: https://doi.org/10.11648/j.ajcbm.20210501.14.

[2] D. A. Mfinanga and L. A. Mwakyami, "Improving the Design of Low Volume Sealed Roads in Tanzania," Tanzania Journal of Engineering and Technology, vol. 31, no. 2, pp. 21–30, 2019, Accessed: Jan. 19, 2025. [Online]. Available: https://www.ajol.info/index.php/tjet/article/view/236727

[3] The United Republic ofTanzania, Ministry of Works, Transport and Communication. MoWTC , Low Volume Roads Design Manual, 1st ed. Dar es Salaam. Tanzania: Goldprints, 2016.

[4] M. Mkonda and X. He, "Yields of the Major Food Crops: Implications to Food Security and Policy in Tanzania's Semi-Arid Agro-Ecological Zone," Sustainability, vol. 9, no. 8, p. 1490, Aug. 2017, doi: https://doi.org/10.3390/su9081490.

[5] K. Fontijn, D. Williamson, E. Mbede, and G. G. J. Ernst, "The Rungwe Volcanic Province, Tanzania – A volcanological review," Journal of African Earth Sciences, vol. 63, no. 1, pp. 12–31, Feb. 2012, doi: https://doi.org/10.1016/j.jafrearsci.2011.11.005.

[6] F. Wagaw Maniyazawal, "Replacing Cinder Gravel as Alternative Base Course Material," American Journal of Construction and Building Materials, vol. 4, no. 1, p. 14, 2020, doi: https://doi.org/10.11648/j.ajcbm.20200401.13.

[7] G. C. Subash , M. Sora, R. Sushmitha , K. B. Suresh , and B. Gowtham , "Certified Organization) Website: www," International Journal of Innovative Research in Science, Engineering and Technology (An ISO, vol. 3297, no. 6, 2017, doi: https://doi.org/10.15680/IJIRSET.2017.0606190.

[8] A. L. Mrema and H. Mboya, "Feasibility of lightweight aggregate concrete for structural and non-structural works in Tanzania," CRC Press eBooks, pp. 1769–1774, Aug. 2013, doi: https://doi.org/10.1201/b15963-318.

[9] F. Albino and J. Biggs, "Magmatic Processes in the East African Rift System: Insights From a 2015–2020 Sentinel-1 InSAR Survey," Geochemistry, Geophysics, Geosystems, vol. 22, no. 3, Mar. 2021, doi: https://doi.org/10.1029/2020gc009488.

[10] The United Republic of Tanzania, Ministry of Works (MoW 2000b), Standard Specification for Road

Works. Tanzania: SSRW TZ, 2000.

[11] G. Berhanu, "Stabilizing cinder gravels for heavily trafficked base course," Zede Journal, vol. 26, pp. 23–29, 2015, Accessed: Feb. 22, 2025. [Online]. Available: https://www.ajol.info/index.php/zj/article/view/120805

[12] H. Zerai, "The Potential Use of Cinder Gravel as a Base Course Material When Stabilized by Volcanic Ash and Lime (The Case of Metehara Area)," Aau.edu.et, Oct. 2015. https://etd.aau.edu.et/items/5f0f15b7-f580-49c7-8be1-607172de50ce (accessed Jan. 03, 2025).

[13] G. J. Hearn, A. Otto, and P. A. K. Greening, "Investigation of the Use of Cinder Gravels in Pavement Layers for Low-Volume Roads, Final Project Report," Final Project Report, TRL Ltd, 2018.

[14] R. Newill, K. Robinson, and K. Akfilu, "Experimental Use of Cinder Gravels on Roads in Ethiopia ," 9th Regional Conference for Africa on Soil Mechanics & Foundation Engineering, Lagos, Nigeria, 1987. Accessed: Nov. 23, 2024. [Online]. Available: https://transport-links.com/wp-content/uploads/2019/11/experimental-use-of-cinder-gravels-on-roads-in-ethiopia-ninth-regional-conference-for-africa-lagos-akinmusuru-j-o-et-al-eds-soil-mechanics-and-foundation.pdf

[15] T. Teshome, "The Use of Natural Pozzolana (Volcanic Ash) to Stabilize Cinder Gravel for a Road Base (Along Modjo - Ziway Route)," Aau.edu.et, Nov. 2015. https://etd.aau.edu.et/items/40e5a3fa-ad3b-4453-bf45-f00193826d45 (accessed Dec. 23, 2024).

[16] Transportation Research Laboratory, TRL, "Overseas Road Note 31, A Guide to the Structural Design of bitumen-surfaced Roads in Tropical and Sub- Tropical Countries," Transport Research Laboratory, Crowthorne Berkshire, United Kingdom, 1993. Accessed: Jan. 10, 2025. [Online]. Available: https://www.trl.co.uk/uploads/trl/documents/ORN31.pdf

[17] Ethiopian Roads Authority, ERA, Manual for Low Volume Roads. Addis Ababa, Ethiopia: ERA, 2017.

[18] Ethiopian Roads Authority, "Guideline for the Use of Cinder Gravels in Pavement Layers for Low Volume Roads," Transport Research Laboratory , Addis Ababa, Ethiopia, 2018.

[19] O. D. Afolayan and O. A. Abidoye, "Causes of Failure on Nigerian Roads: A Review," Journal of Advancement in Engineering and Technology, vol. 5, no. 4, 2017.

[20] The United Republic of Tanzania, Ministry of Works (MoW 2000a), Laboratory Testing Manual. Dar es Salaam, Tanzania: Central Material Laboratory, 2000.

[21] Ministry of Transport and Public Works, "Republic of Malawi Ministry of Transport and Public Works Low Volume Roads Manual Volume 1 Pavement Design," Tshwane University of Technology, Pretoria, South Africa, 2020. Accessed: Dec. 23, 2024. [Online]. Available: https://www.research4cap.org/wp-content/uploads/ral/RoadsAuthorityMalawi-2020-LowVolumeRoadsManual-Volume1-200820-compressed.pdf

[22] J. G. Speight, Asphalt materials science and technology, 1st ed. Oxford: Butterworth-Heinemann, 2016.

[23] Whitehelmet, "Aggregate Impact Test Procedure for Determining AIV as per IS 2386 Part-4," www.constructioncivil.com, Jan. 15, 2021. https://www.constructioncivil.com/aggregate-impact-test-procedure/ (accessed Feb. 10, 2025).

[24] The United Republic of Tanzania, Ministry of Works (MoW), Pavement and Materials Design Manual. Dar es Salaam, Tanzania: Ministry of Works, 1999.

[25] D. H. Chengula, "The Use of Blended Cinder Aggregates for Concrete Mixes," International Journal of

Sciences: Basic and Applied Research (IJSBAR) , vol. 61, no. 1, pp. 44–61, Jan. 2022.

[26] B. Baskette, T. Renfro, K. Isenberg, and L. Skaggs, Hot Mix Asphalt Mix Design Certification, 24th ed. Tennessee: TDOT, Department of Transportation, Division of Materials and Tests, 2024.

[27] F. L. Roberts, P. S. Kandhal, E. R. Brown, D.-Y. . Lee, and T. W. Kennedy, “Hot Mix Asphalt Materials, Mixture Design and Construction. Second Edition,” trid.trb.org, 1996, Available: https://trid.trb.org/view/473852

[28] American Association of State Highway and Transportation Officials, AASHTO, Standard Specification for Transportation Materials and Method of Sampling and Testing, Part 1 Specifications, 20th ed. Washington D. C: American Association of State Highway and Transportation Officials., 2000.

[29] ASTM International, Test Method for Marshall Stability and Flow of Asphalt mixtures’, Annual Book of ASTM Standards, 4th ed., vol. 3. ASTM Standard, 2022.

[30] D. H. Chengula, “Effective Utilization of Reclaimed Asphalt Concrete for Road Works (Dissertation),” Dissertation, LAP Lambert Academic Publishing, 2018.

[31] Asphalt Institute, Superpave Mix Design (MS-2), Asphalt Mix Design Methods, 7th ed., vol. 2. USA: Library of Congress, 2014.

[32] American Association of State Highway and Transportation Officials (AASHTO), M323-20, Standard Specification for Super Pave Volumetric Mix Design. Washington DC: AASHTO, 2020.