THE EFFECT OF COW DUNG ASH AND BANANA PEELS ASH AS A FILLER ON MARSHALL AND VOLUMETRIC PROPERTIES OF HOT MIX ASPHALT

BY

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21/U/GMES/14501/PE

A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND

GRADUATE TRAINING IN PARTIAL FULFILMNT OF TH REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN STRUCTURAL ENGINEERING DEGREE OF KYAMBOGO UNIVERSITY.

MAY, 2024

DECLARATION

I **Ntwirenabo Coleb**, hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgement has been made in the text and reference list.

Signed ……………………………… Date……………………………….

APPROVAL

The undersigned approve that they have read and hereby recommend for submission to the Directorate of Research and Graduate Training of Kyambogo University, a dissertation entitled; **Effect of Cow Dung Ash and Banana Peels Ash as fillers on Marshall and Volumetric properties of Hot Mix Asphalt** in fulfilment of the requirements for the award of Master of Science in Structural Engineering Degree of Kyambogo University.

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ACKNOWLEDGEMENTS

I am grateful to my Supervisor Dr. Vicent Ssenyondo for his valuable guidance, expert advice, encouragement and not giving up on me. He provided me with all the knowledge, experience and support that I needed to accomplish this research. It was a great pleasure for me to have him as my supervisor. His help and support are really appreciated.

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AASHTO	American Association of State Highway and Transport Officials
AC	Asphalt Concrete
ACV	Aggregate Crushing Value
ASTM	American Society for Testing and Materials
BPA	Banana Peels Ash
BS	British Standards
CDA	Cow Dung Ash
HMA	Hot Mix Asphalt
ITS	Indirect Tensile Strength
ITSR	Indirect Tensile Strength Ratio
MSWI	Municipal Solid Waste Incinerator
SDGs	Sustainable Development Goals
SMA	Stone matrix asphalt
TRL	Transport Research Laboratory
UNRA	Uganda National Roads Authority
VFB	Voids Filled with Bitumen
VMA	Voids in Mineral Aggregates

ABSTRACT

Increased cost of construction materials for flexible pavements has urged researchers to opt for alternative filler materials instead of the conventional cement filler towards greener materials. In this work, cow dung ash (CDA) and banana peels ash (BPA) were investigated as potential substitutes at varied percentage filler contents. The first approach involved replacing the 4 % cement filler content with 25 %, 50 %, 75 % and 100 % with either BPA or CDA filler materials in the Hot Mix Asphalt (HMA). Secondly, the cement filler material within the prepared HMA was fully replaced with either BPA or CDA filler materials at varied amounts of 2 %, 4 %, 6 % and 8 % each. Marshal and volumetric properties including voids in the mix, flow, voids in the mineral aggregate, stability, and voids filled with bitumen in both scenarios were evaluated. Indirect tensile strength (ITS) was obtained for the full cement filler material replacement condition. For partially replacing the cement filler material, optimum parameters were revealed at 50 % CDA and 50 % BPA. For 50 % CDA, voids in the mix, voids in the mineral aggregate (VMA), voids filled with bitumen (VFB), stability and flow were 4.4 %, 16.2 %, 72 %, 16.7 kN, and 3.6 mm respectively. Meanwhile, for 50% BPA, voids in the mix, VMA, VFB, stability and flow were 4.4 %, 16.1 %,72.7 %, 10.63 kN and 3.37 mm. On the other hand, optimum parameters for fully replacing the cement filler material were obtained at 4 % CDA and 4 % BPA. For 4 % CDA, voids in the mix, VMA, VFB, stability and flow were 3.89 %, 16.9 %, 77 %, 13.9 kN, and 3.61 mm respectively. Meanwhile, for 4% BPA, voids in the mix, VMA, VFB, stability and flow were 4.06 %, 16.98 %,76.08 %, 10.7 kN and 3.31 mm. An ITS of 93 % and 98 % for 4 % CDA and 4 % BPA were noted respectively. From the test results, the developed CDA and BPA materials met the Uganda MoWT general specifications for roads and bridges for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS). Thus, the green filler materials portrayed a viable potentiality to substitute the cement filler in the HMA which fosters reduction in the overall cost of road construction materials. This will have a positive impact on the Sustainable Development Goals, specifically targeting SDG 9 (pertaining to Industry, Innovation, and Infrastructure), SDG 11 (focusing on Sustainable Cities and Communities), and SDG 13 (centered around Climate Action).

Keywords: Experimental tests, Cow Dung Ash, Banana Peels Ash, Hot Mix Asphalt, Marshall Properties, Volumetric Properties

CHAPTER ONE: INTRODUCTION

1.1 Background

Road transport is a popular means of transport for goods and people in most parts in the World. This road transport reliance has resulted into disproportionate growth in traffic levels world over and this increase has caused distresses on the pavement resulting into a reduction in the lifespan and necessitates expensive surface layer maintenance (Saeed *et al.*, 2017). Uganda is a land locked country and largely depends on road transport. The other means of transport in Uganda include railway, water, air but these ones are not fully operational. Worldwide, the commonest means of transportation of both goods and people is road transport and this increasing demand for transportation has led to increased traffic loading on roads. This continuous increase in loading on the roads, has impelled faster and continuous deterioration of the pavements. Asphalt concrete road surfacing is commonly used because of its potential to withstand plastic deformation and cracking caused by the load from traffic. Being a component of HMA, filler plays a role in filling the spaces between larger and smaller aggregates, thereby enhancing overall density. Most common materials used as fillers include cement, lime and limestone. According to Alamri, Lu and Xin (2020), choosing suitable materials for creating hot mix asphalt (HMA) is crucial in achieving the desired, resilient pavements that can support sustainable traffic loads for development over time. Traditional additives like cement, lime, and limestone dust are employed primarily for various construction needs, particularly within the housing sector. Given the worldwide housing crisis as predicted by world bank of over

1.6 billion people by 2025, investors have moved very fast to invest in the housing industry to try to fill this gap increasing the demand for the materials. According to the Centre for affordable housing Africa, the current housing deficit in Uganda is estimated at 2.4 million housing units with the bulk of these falling in the affordable housing segment. Because of the depletion of raw materials for cement production and the growing demand, cement prices in Uganda have surged by more than 40 % in the past two years (Duncan, 2022).

Given the expensive nature of traditional additives like cement, lime, and limestone dust, which are commonly used in various construction applications, the asphalt industry has increasingly turned to incorporating alternative waste materials to enhance the characteristics of HMA. This approach has become widespread and has demonstrated improved performance in pavement structure, attributed to its growing utilization (Liu *et al.*, 2012).

Lately, there has been a growing focus in research on substituting mineral fillers with waste materials, driven by the continuously rising expenses associated with traditional fillers. An example of such wastes is cow dung, glass powder, cow bone, rice husks, industrial slag among others that have become a burden to the environment and health of the people for example cow dung has been found to cause health problems in human beings because it contains hazardous microbes (Fan *et al.*, 2019). This research therefore seeks to investigate the utilization of cow dung ash and banana peel ash fillers with respect to the requirements for HMA.

1.2 Problem Statement

Uganda has a total road network of 40,800 km of which only 5591 km (13.7%) are paved. In Uganda, the average unit cost per km ranges between 3.5 - 5.5 billion which is costly as compared to other East African Countries (Wamala, 2022). One of the reasons for this high cost is depending on manufactured construction materials which are normally imported. Asphalt concrete is one of the materials commonly used for road paving and it constitutes of aggregates, filler and binder (bitumen). Materials commonly used as fillers are cement, lime and limestone dust. These materials are quite expensive, and their production process has a negative impact on the environment (Sagastume Gutiérrez *et al.*, 2012). World Health Organization estimates 5 % of total released carbon dioxide into atmosphere to be from the cement industry and cement is one of the fillers used in asphalt concrete production (Sizirici *et al.*, 2021).

Uganda has 14.2 million cows (NAADS, 2023) and produces 4.3 to 10.5 million bananas annually (FAO, 2023). This leads to generation of a large amount of cow dung and banana peels as wastes leading to disposal challenges that incur both significant financial and environmental costs.

There are attempts to utilize agricultural wastes and limitation of industrial activities to reduce the negative impacts on environment. Therefore, utilizing cow dung and banana peel ash as an alternative filler for replacement of cement in asphalt concrete would go a long way in alleviating the high cost of paving roads and disposal. The objective of this study is to assess the efficiency of utilizing cow dung and ash from banana peels as alternative fillers in Hot Mix Asphalt, replacing cement.

1.3 Research Objectives

1.3.1 Main Objective

The main objective was to evaluate the effect of utilizing cow dung ash and banana peels ash fillers as eco-friendly alternatives to cement filler in the hot mix asphalt used for construction of low traffic roads (< $1\text{x}10^6$ ESAs).

1.3.2 Specific objective

The specific objectives of this investigation were to:

i. Characterize asphalt concrete constituents based on physical and mechanical properties,

ii. Determine the effect of cow dung ash and banana peels ash on Marshall and volumetric properties of hot mix asphalt in varying percentages,

iii. Determine the optimum percentages for cow dung ash and banana peels ash filler materials for use in the hot mix asphalt and

iv. Compare the properties of cow dung ash and banana peels ash with the conventional cement filler and Uganda’s Ministry of Works general specifications of roads and bridges.

1.4 Research Questions

1. What are the characteristics of CDA and BPA as filler materials in HMA?
2. What are the effects of CDA and BPA when used as fillers on Marshall and volumetric properties of HMA?
3. What are the optimum percentages of CDA and BPA for use as fillers in HMA?
4. How do the results obtained in all the cases compare with standard specifications?

1.5 Research Justification

A high cost of paving roads in Uganda has resulted into a bigger percentage (86 %) of roads unpaved and also increased agricultural activities has resulted into generation of a lot of wastes which are costly to dispose. This research provided precise technical information on utilization of cow dung ash and Banana peels ash as alternative of cement as filler in HMA and promoted adoption of cost-effective, sustainable, and eco-friendly construction materials. This therefore sought to increase the paved road length and also a reduction in the cost of disposing agricultural wastes.

1.6 Significance

This study fostered development of a class of asphalt concrete with improved properties using cow dung ash and banana peels ash as fillers. The results obtained in this research act as a starting point for both practitioners and researchers to utilize cow dung and banana peels in production of asphalt concrete that will be a great benefit to Uganda and East Africa at large. This will help in reducing the cost of paving roads and hence increased percentage of paved roads. This research will be more useful to areas in Uganda with high banana production and cows like western and central Uganda. This will lead to improved community access to facilities like centres of administration, hospitals, schools and markets and eradication of respiratory tract infections which come as a result of dust and attainment of Sustainable Development Goal 11, which focuses on creating sustainable cities and communities.

1.7 Scope of the Study

This research was carried out in Lira District, Uganda Country in Africa. Banana peels and Cow dung were obtained from Bushenyi Banana factory and local farms respectively. This study was limited to investigating the potentiality of cow dung ash and Banana peels ash as fillers in HMA in attempt to reduce or stop use of cement as filler. The research was conducted between October 2022 and July 2023.

1.8 Conceptual framework

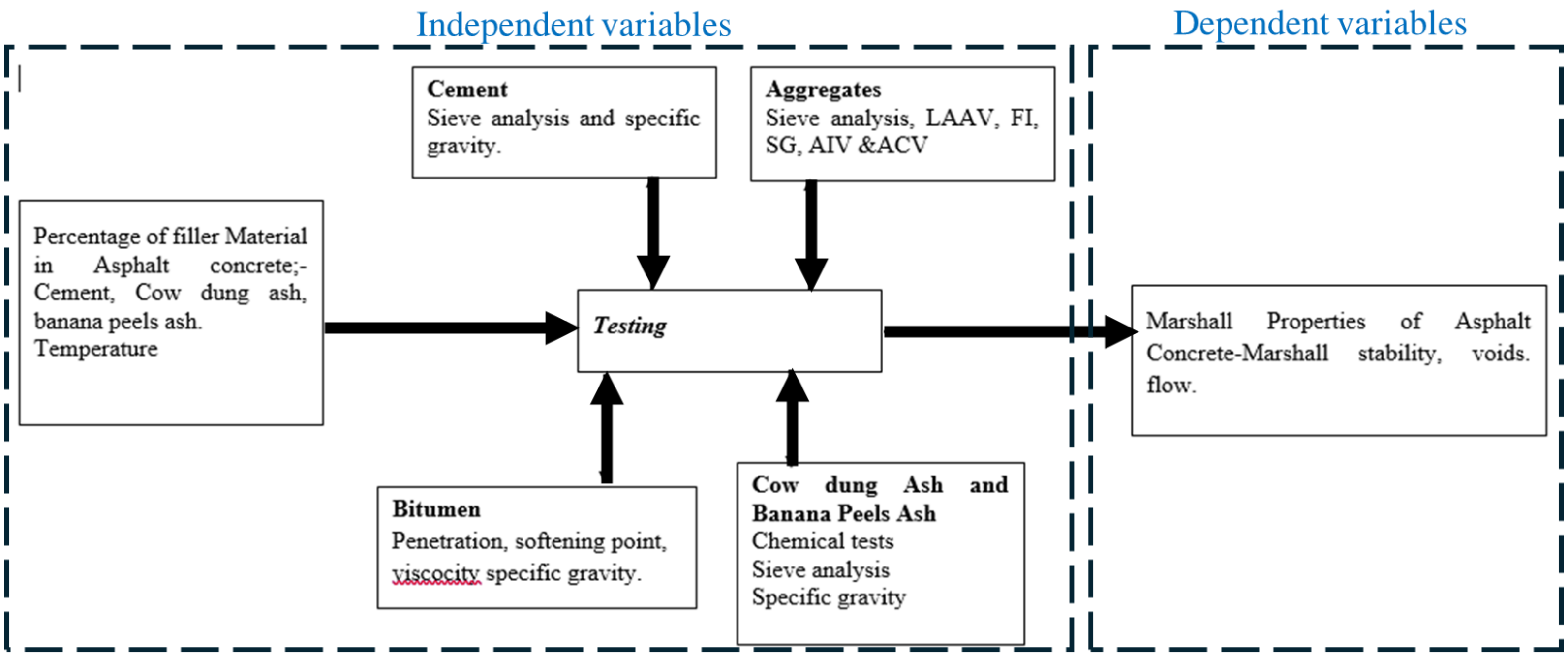

Figure 1.1: Research Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter gives a review of related works for a better understanding of the importance of additive within hot mix asphalt. Based on this and the objectives of this research, the literature review is structured into the concept of alternative materials as filler specifically the use of waste materials (cow dung ash and banana peel ash). The chapter ends with a section on identified gaps and the envisaged contribution of the current research project.

2.2 Road Classification

Roads are categorized according to factors such as the materials used in construction, their geographical placement, intended purpose, traffic intensity, width, cost-effectiveness, traffic composition, structural flexibility, terrain characteristics, and more. In the context of Uganda, location-wise distinctions include National Roads, District Roads, Urban Roads, and Community Roads.

Roads can also be categorized based on their structural characteristics, distinguishing between rigid pavement roads and flexible pavement roads. Flexible pavements consist of layers including a surface course, base course, subbase course, and subgrade. In contrast, rigid pavements are composed of a concrete surface course, a base course, and a subgrade. For every pavement, the upper layers are made up of superior materials. The strength of the material reduces as you approach the subgrade. This is done so to protect the subgrade from excessive loads from traffic loading which can cause subgrade deformation (Eisa *et al.*, 2022).

Rigid pavements have better load-carrying capacity and last longer as compared to flexible pavements, However, their initial costs are very high, and they are difficult to repair. Flexible pavements' initial cost is relatively low and is easy to repair and therefore preferred by developing countries. Uganda, inclusive prefers flexible pavements to rigid pavements.

2.3 Road Layer

A road consists of materials compacted in layers of increasing strength as shown in the Figure 2.1.

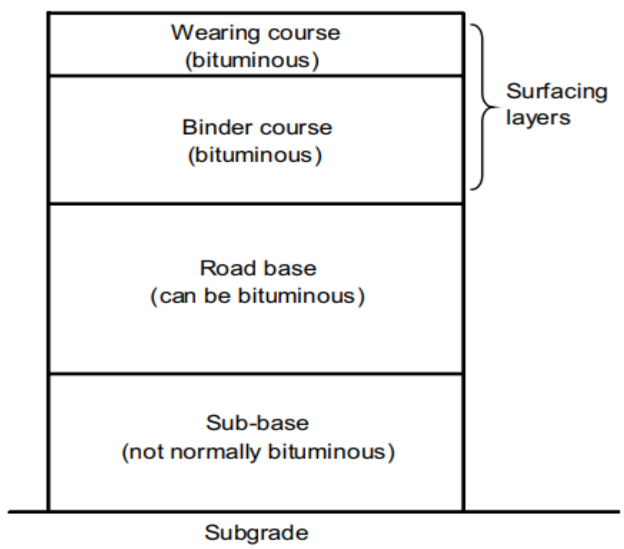

Figure 2.1: Pavement layers (UK Department for International Development, 2002)

2.3.1 Wearing Course

This constitutes the topmost stratum of the road, typically comprised of a bituminous surface dressing or a coating of pre-mixed bituminous material (UK Department for International Development, 2002). This is the layer where this research was focussed.

When using premixed bituminous material (for this research is Hot Mix Asphalt), material wise it consists of course aggregates, fine aggregates, filler and a paving grade bitumen.

2.3.2 Base Course

Rote Note 31 characterizes this stratum as the primary load distribution layer of the pavement. Its constitution may include crushed stones, gravel, soil with gravel content, fragmented rock, sand, and clay soils treated with cement, lime, or bitumen for stabilization.

2.3.3 Subbase

Found beneath the base course, this layer serves as a secondary load distribution stratum. It is constructed using materials such as gravel and enhanced gravel, among various others. Additionally, this layer provides safeguarding for the subgrade layer against potential damage caused by construction-related traffic.

2.3.4 Subgrade

This constitutes the initial layer of the road. It can be an existing material or an imported and strengthened material to improve its load-carrying capacity. The subgrade should be able to protect other layers above without deforming.

2.4 Hot Mix Asphalt (HMA)

It's the most important layer in pavement structure and should have predictable performance and good quality. Having a strong ability to resist deformation and fatigue while being capable of enduring strain are among the attributes this layer needs to possess. HMA is composed of mineral aggregates, asphalt binder (cement), and air, and their ratios should be balanced to ensure that the resulting properties of the mixture lead to optimal performance. (Huang, Li and Shu, 2006).

2.4.1 Components of Hot Mix Asphalt

Road note 19 (UK Department for International Development, 2002) describes HMA as a constituent of the following in an appropriate mix:

- coarse aggregates of size larger than 2.36 mm sieve size-coarse
- fine aggregates of size lower than 2.36 mm but more than 0.075mm
- filler size finer than 0.075 mm and can be crushed stone dust, cement or lime.
- a paving grade binder material (bitumen) chosen according to climatic and loading conditions

a) Aggregates

According to ASTM D8, aggregate is described as a mixture of granular elements, encompassing materials like sand, gravel, crushed stone, slag, or shell. When mixed with a binding substance like cement, it creates mortars or concrete, or it can be used independently in applications such as base courses and railroad ballasts (ASTM, 2017).

The source of course aggregates should be from the process of crushing solid, unaffected rock or indigenous gravel possessing specific attributes of clean and free from clay, angular and not excessively flaky, strong, high resistance to abrasion, non-absorptive and good affinity with bitumen (UK Department for International Development, 2002).

The limits of the above properties to produce the desired mix and good performance during loading as per Uganda's general specification for roads and bridge works (2005), (Bagonza, 2005) and road note 19 (UK Department for International Development, 2002) is as shown in Table 2.1.

Aggregates act as reinforcement in the HMA and they form the largest percentage by weight of the mix (90 – 95 %) (Khan *et al.,* 2022). A higher proportion plays a significant role in enhancing resistance against rutting and yields favourable shear strength. The ability to withstand rutting is associated with the texture and form; therefore, achieving greater resistance necessitates a rough texture and a cubical shape. Resistance to fracturing under heavy traffic loading, polishing, and abrasion is due to the hardness of the aggregates. Research and field tests have shown that densely graded aggregates offer high frictional resistance and stability of the mix (Pan *et al.*, 2023).

In Hot Mix Asphalt (HMA), aggregates gradation holds paramount importance and is characterized as the arrangement of particle sizes, quantified as a percentage of the overall weight of the sample. Gradation is one of the main stages in designing a good mix of HMA (Sapkota *et al.*, 2023). Consideration must be done to control the voids in the mix. These voids are important because they accommodate asphalt film thickness on each particle and allow for a given air void for thermal expansion within the mix. A good gradation can predict the final volumetric properties of the mix but if the specific gravity of the different constituent differs by more than 0.2, the mix may have different volumetric properties. The volumetric properties are air voids, voids in mineral aggregates, voids filled with bitumen, etc (Asphalt Institute MS-2, 2014). Uganda's Ministry of Works and Transport (MoWT) General Specifications for Road and Bridge works (2005) provides limitations for gradation for the final mix to have acceptable volumetric properties as shown in Table 2.2 (Bagonza, 2005).

Table 2.1: Required properties for HMA aggregates

Property	**Test**	**Limits**	
		Wearing Course	
		Road note 19	Uganda's MoWT general specification for roads and bridges
Cleanliness	Sand equivalent: (for materials with particle size less than 4.75 mm) Traffic loading < 1.5×10^6 ESAs Traffic loading > 1.5×10^6 ESAs	> 35 > 40	 > 45
	(Material passing 0.425 mm sieve) Plasticity index Linear shrinkage %	 < 4 < 2	 < 4
Particle shape	Flakiness index	< 35	< 25
Strength	Aggregate Crushing Value (ACV) Aggregate Impact Value (AIV) 10% FACT (dry) kN Los Angeles Abrasion (LAA)	< 25 < 25 >160 < 30	 > 110
Absorption	Water absorption	< 2	< 2
Soundness	Sodium sulphate test: Course Fine	< 10 < 16	< 12
Bitumen affinity	Coating and Stripping test	> 95 %	> 95 %

Source: Road note 19 (UK Department for International Development, 2002); Uganda's MoWT general specification for roads and bridges (Bagonza, 2005)

Table 2.2: Gradation limits for aggregates for Asphalt concrete

Sieve size (mm)	Asphalt concrete, continuously graded		
	AC20	**AC14**	**AC10**
28	100	-	-
20	80-100	100	-
14	60-80	85-100	100
10	50-70	72-94	85-100
5.0	36-56	52-72	55-72
2.36	28-44	37-55	38-57
1.18	20-34	26-41	27-42
0.600	15-27	16-28	18-32
0.300	10-20	12-20	13-23
0.150	5-13	8-15	9-16
0.075	2-6	4-10	4-10
Aggregate	95%	94.5%	94%
Bitumen content ASTM 2172-88	5%	5.5%	6%

Source: MoWT general specification for roads and bridges, 2005 (Bagonza, 2005)

b) Filler

This is material used in HMA with at least 70 % by mass of the particles passing through the 0.075 mm sieve, completely pass through the 0.600 mm sieve, and possess a bulk density in toluene ranging from 0.5 to 0.9 g/ml according to the MoWT General Specifications for Road and Bridge works, (2005). Mineral fillers are mixed with the aggregates before wetting with the binder.

Filler plays an important role of reducing the voids in the resultant mix. Nevertheless, when the mineral filler has a finer consistency than the thickness of the asphalt film, it creates a mastic mortar that enhances the rigidity of the mixture. However, when the filler surpasses the thickness of the asphalt film, it functions like mineral aggregates and occupies the gaps within the mixture. This aids in diminishing both cracking and rutting. (Muniandy *et al.*, 2012).

Frequently employed fillers in practical applications include lime, cement, quarry dust, slag cement, and fly ash, among various alternatives. Fillers hold significant influence over the attributes and conduct of Hot Mix Asphalt (HMA), particularly in relation to Voids in Mineral Aggregate (VMA). They contribute to heightened asphalt rigidity while impacting factors like workability and longevity. The effectiveness of a filler hinges on its chemical and physical attributes, including grading, geometric characteristics, and shape.

Chemically, fillers are categorised as inert/inactive and active considering how they react when get in contact with bitumen.

Inert filler has very little or no chemical reaction with bitumen. An example is limestone.

Active fillers are reactive to bitumen and water hence changing the structure of bitumen and an example is cement. Calcium Oxide and Silicon dioxide are the chemical compounds in active fillers which lead to the creation of hydraulic binders with HMA mix. Calcium oxide also reacts with water and form calcium hydroxide which accelerates curing.

$$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(l)} \text{ .... Equation 2.1}$$

The presence of SiO_2 in filler leads to the creation of dense microstructures which reduce air voids, hence increasing strength.

Availability of CaO, SiO_2 and Al_2O_3 are responsible for improved strength with short setting time. However, the presence of Fe_2O_3 filler reduces the compressive strength.

The conventional mineral fillers used in practice such as cement, lime, and granite powder are expensive, and this has had an impact on the cost of paving roads. Therefore, studies are being undertaken to assess the suitability of agricultural wastes such as banana leaves ash, cow dung ash, rice husk ash, banana peels ash, and rice husk ash among others for use as fillers in hot mix asphalt (Sargin *et al.*, 2013; Nemaleu *et al.*, 2021; Abdulrasool *et al.*, 2022; Tavares *et al.*, 2022).

c) Paving grade binder material (Bitumen)

The binder is a material that coats and holds together aggregate particles and the mineral filler to form a mixture that is resistant to climatic conditions and traffic loading. The performance of the binder is influenced by changes in temperature, susceptibility, visco-elasticity and aging of the binder (Feng *et al.*, 2020). Bitumen serves as the binding agent in hot mix asphalt. The bitumen grades used in preparation of HMA are 30/40, 40/50, 50/70, 60/70, 80/100 and 100/120 where for instance 30/40 implies that it's a bitumen type whose penetration lie between 30 - 40 mm as further presented in Table 2.3 (Singh *et al.*, 2020). Bitumen exhibits elasticity when subjected to low temperatures and takes on a viscous fluid-like behaviour at higher temperatures. It becomes more rigid in colder conditions and when subjected to shorter periods of loading. Binder material must possess three characteristics of consistency, purity and safety. The sourcing and subsequent graving have been its penetration but recently viscosity grading has been more accurate in specifying binder consistency and temperature susceptibility. In this research, a penetration-graded bitumen was used and the requirements for penetration-graded bitumen as per Overseas Road Note 19, (UK Department for International Development, 2002) are shown in Table 2.3. These properties help in the choice of bitumen for a given region and also the temperature at which bitumen can be handled safely.

Table 2.3: Minimum requirement for penetration grade bitumen (UK Department for International Development, 2002)

Test		Test method (ASTM)	Penetration grade		
			40/50	60/70	80/100
Penetration at 25 ºC		D 5	40-50	60 - 70	80 - 100
Softening point (ºC)		D 36	49 - 59	46 - 56	42 - 51
Flashpoint (ºC)	Min	D 92	232	232	219
Solubility in trichloroethylene (%)	Min	D 2042	99	99	99
TFOT heating for 5h at 163 ºC		D 1754			
a. Loss by mass (%)	Max		0.5	0.5	0.8
b. Penetration (% of original)	Min	D 5	58	54	50
c. Ductility at 25 ºC	Min	D 133	-	50	75

d) Cow Dung

Dung is excreta from cows, and it is normally dark green in colour and bulky when fresh. It possesses a significant amount of ash, minimal volatile substances post-combustion, low carbon content, and a low combustion ratio. It contains high moisture content. In terms of chemical properties, cow dung presents a high nitrogen, potassium, phosphorous, and calcium (Gupta, Aneja and Rana, 2016). According to Garg and Mudgal (2007), the carbon-to-nitrogen ratio of cow dung is high. It also contains 10.8 % calcium, 8 % phosphorus, 84.1 % zinc and 21.7% copper.

e) Banana peels

Production of banana in the world is 145 million tonnes. Uganda is among the best 10 banana-producing countries in the world with a production capacity of about 4.5 - 10.5 million tonnes annually (Silva and Gurría, 2016). In western Uganda, the production of bananas is at 68%, the central region at 23%, the Eastern region at 8% and the Northern 1%. Since most are peeled before there is a huge concern regarding disposal of the banana peels.

f) Cement

Cement is the second most commonly used filler in HMA next to lime, however, according to Fan *et al.*(2019), Cement improves the effectiveness of Hot Mix Asphalt in relation to its resistance to moisture-induced changes and its ability to mitigate rutting. The commonly used cement is ordinary Portland cement. In Uganda, the commonly used filler is cement. Because of the depletion of raw materials for cement production and the rising demand, cement prices have surged by more than 50% in the past two years.

2.5 Empirical Review

Alayaki (2020) examined the impact of Cow Dung Ash (CDA) and Polyethylene Terephthalate (PET) as alternative filler and binder, respectively, on the Volumetric and Marshall Properties of Asphalt Concrete, when incorporated individually. CDA was introduced to replace filler at varying levels of 4%, 6%, 8%, 12%, and 20% in one mixture, while PET was used to substitute bitumen at levels of 3%, 6%, 9%, 12%, and 15% in another. Findings demonstrated that replacing filler with CDA at 4% and 8% exhibited potential for application in Asphalt Concrete. In contrast, a replacement range of 6% to 15% of bitumen with PET was recommended for utilization in the wearing course for roads with medium traffic levels.

Abdulrasool *et al***.** (2022) explored the impact of cow dung ash (CDA) as a filler on the mechanical attributes of Hot Mixed Asphalt. This investigation involved the partial substitution of limestone filler with CDA across a spectrum of percentages: 0%, 10%, 20%, 30%, 40%, 50%, 60%, 80%, and 100%. The research evaluated various material properties encompassing stability, flow, voids in mineral aggregate, theoretical maximum specific gravity, and air voids. Results revealed that a 50% replacement yielded the highest Marshall stability value of 11.11 and the lowest flow of 3 mm, when compared to the reference mix. Conclusively, the study determined that cow dung ash holds the potential to function as a filler, effectively modifying the mechanical characteristics of Hot Mix Asphalt.

Ali (2022) investigated the effect of utilizing banana peels powder as well as banana peels ash as concrete admixtures. The tensile strength properties of concrete improved at 0.8% and 1.25% additions of banana peels powder and banana peels ash, respectively. It was also found out that the peels ash increased the concrete setting time.

Tavares *et al.*(2022) examined the impacts of incorporating banana leaves ash (BLA) as a viable option for use in concrete, involving its partial replacement of cement. The review indicated that BLA exerts a favourable influence on concrete properties, rendering it a suitable candidate as a supplementary cementitious material, with optimal effects observed at a 1.25% replacement rate. Moreover, the utilization of BLA as a partial cement substitute was found to enhance tensile strength as well.

Tessema, Wolelaw and Alene (2022) conducted an experimental assessment of Coffee Husk Ash (CHA) as a potential filler for Hot Mix Asphalt. The research initially employed Crushed Stone Dust (CSD) as a conventional filler, achieving a 6.5% mass percentage of the overall mixture, which provided the highest stability. Subsequently, CSD was partially replaced with CHA at varying levels of 25%, 50%, 75%, and 100%, followed by testing using the Marshall stability method. The impact of filler on Asphalt concrete when exposed to moisture was also investigated. The study determined that a partial replacement rate of 75% resulted in optimal material properties encompassing stability, flow, air voids, VFA (voids filled with asphalt), and bulk density. These values were measured at 16.820 kN, 4.983 mm, 4.435%, and 73.717%, respectively, at the ideal bitumen content of 5.57 %.

Sumardi, Rachman and Tanijaya (2019) investigated the utilization of bagasse ash within Asphalt concrete through partial replacement of filler, carried out at levels of 25%, 50%, 75%, and 100%. The experiments adhered to both Indonesian National Standard and ASTM protocols. For the Asphalt Concrete wearing course, the material makeup comprised 6.5% asphalt, 37.05% aggregates, 50.60% fine aggregates, and 5.85% filler. On the other hand, the Asphalt Concrete binder course consisted of 6.5% asphalt, 42.64% coarse aggregates, 44.95% fine aggregates, and 5.91% filler. The study concluded that the integration of bagasse ash met the stipulated requirements for utilization in both the asphalt concrete wearing course and asphalt concrete binder course, respectively.

Al-Gurah and Al-Humeidawi (2021) investigated the influence of various filler types on the mechanical attributes of Hot Mix Asphalt (HMA). Rice Husk Ash (RHA), limestone, and Ordinary Portland Cement were employed as fillers in the asphalt mixture. Diverse replacement levels of 25%, 50%, 75%, and 100% were employed, and assessments of material properties were executed following ASTM and ASHTO standards. The outcomes indicated that the most favourable material properties were achieved with a 25% replacement of RHA and a 75% replacement of limestone as fillers, offering optimal results.

Wang, Guo and Tan (2018) considered the use of cement as a mineral filler substitute in asphalt pavement. The authors carried out property’s tests, mix design and performance test on the resultant mix. The findings were that cement is relatable to mineral filler in terms of mix’s physical and volumetric properties. The study employed a bitumen content of 5%, and the test outcomes displayed stability reaching 78.9%, along with a freeze-thaw splitting test result of 74.4%, both of which met the established criteria. Additional data, such as a dynamic stability measurement of 1169 time/mm and a seepage coefficient of 63.4 ml/m, showcased a commendable functional performance. This further established that cement serves as a viable filler option in asphalt concrete, surpassing the performance of mineral filler.

Guha and Assaf (2020) studied ordinary Portland cement (OPC) as a mineral filler substitute in asphalt concrete in order to improve its rigidity rutting and shoving distresses. The study utilises replacement percentages of 0, 2, 4, and 6% and the use of gyratory compactor and asphalt pavement rutting analyser to determine performance of three mixes. The results showed that OPC a more stable mix compared to conventional mineral filler and has a higher resulting modulus of rigidity. This makes it suitable to be use as a filler in HMA in hot regions.

Mohammad Harun-Or-Rashid and Mohayminul Islam (2020) examined existing research on a range of waste materials, including fly ash, bagasse ash, marble dust, stone dust, kiln dust, waste concrete dust, bio gypsum, ceramic dust, and foundry sand, utilized as fillers in Hot Mix Asphalt (HMA). The outcomes of these studies were deemed favourable. The investigation centred around marshal mix design, employing the mentioned materials to assess different physical and volumetric properties across various mixes.

Within the previous studies that have investigated the use of BPA and or CDA as alternative construction materials, chemical and physical properties of these filler materials have not widely been explored. Also, no studies have considered using them as composite filler additions.

2.6 Research Gaps

According to the reviewed literature, extensive investigations have been conducted concerning the utilization of different mineral fillers such as limestone dust, yielding satisfactory outcomes. However, limited studies have been directed towards the application of organic fillers such as cow dung ash, bagasse ash, coffee husk ash, rice husk ash and banana peels ash in the Hot Mix Asphalt (HMA). Also, there exists few studies utilizing cow dung ash and banana peels ash with investigating the different Marshal and volumetric characteristics of the resulting HMA. Notably, all prior studies have been conducted in countries other than Uganda, where the feed for cows differs from that used by Ugandan farmers. With this and the high cost of existing asphalt construction materials that leads to a bigger percentage of unpaved roads, in this study the use of cow dung ash (CDA) and banana peels ash (BPA) as fillers has been undertaken to determine their effect on the resultant Marshal and volumetric properties of the Hot Mix Asphalt.

CHAPTER THREE: MATERIALS AND METHODS

3.0 Introduction

In this chapter, various materials, experimental techniques and procedures followed during the testing are presented. ASTM, AASHTO and British standards were used for testing because of their common use for material testing in Uganda.

3.1 Research design

In this study, cow dung ash and banana peels ash fillers Marshall and volumetric properties were investigated for their application in the Hot Mix Asphalt. This was based on Marshall mix design and asphalt wearing course of class AC/14. Materials used were machine crushed aggregates of varying sizes (10 – 20 mm, 6 – 10 mm, 3 – 6 mm and 0 – 3 mm), fillers (cement, cow dung ash and banana peels ash) and bitumen of penetration grade 50/70.

Properties of the materials were tested using ASTM, British Standards and AASHTO (*AASHTO-American Association of State Highway and Transportation Officials*, 2018) guidelines.

The following described research activities conducted are as schematized in Figure 3.1.

a) Material source identification, acquisition and identification.

b) Material characterisation, that is determination of individual material physical and chemical properties.

c) Determination of the effect of CDA and BPA on the Marshall and Volumetric properties of HMA through:

i. Determining optimal bitumen content using the conventional filler (cement)

ii. Utilising the optimal bitumen content on partially replaced conventional filler (cement) with alternative fillers (CDA and BPA) and

iii. Determination of optimal filler percentage when varying organic filler (CDA and BPA) percentages from 2 % to 8 % at an interval of 2 %.

d) Data analysis using Excel spread sheets and R software.

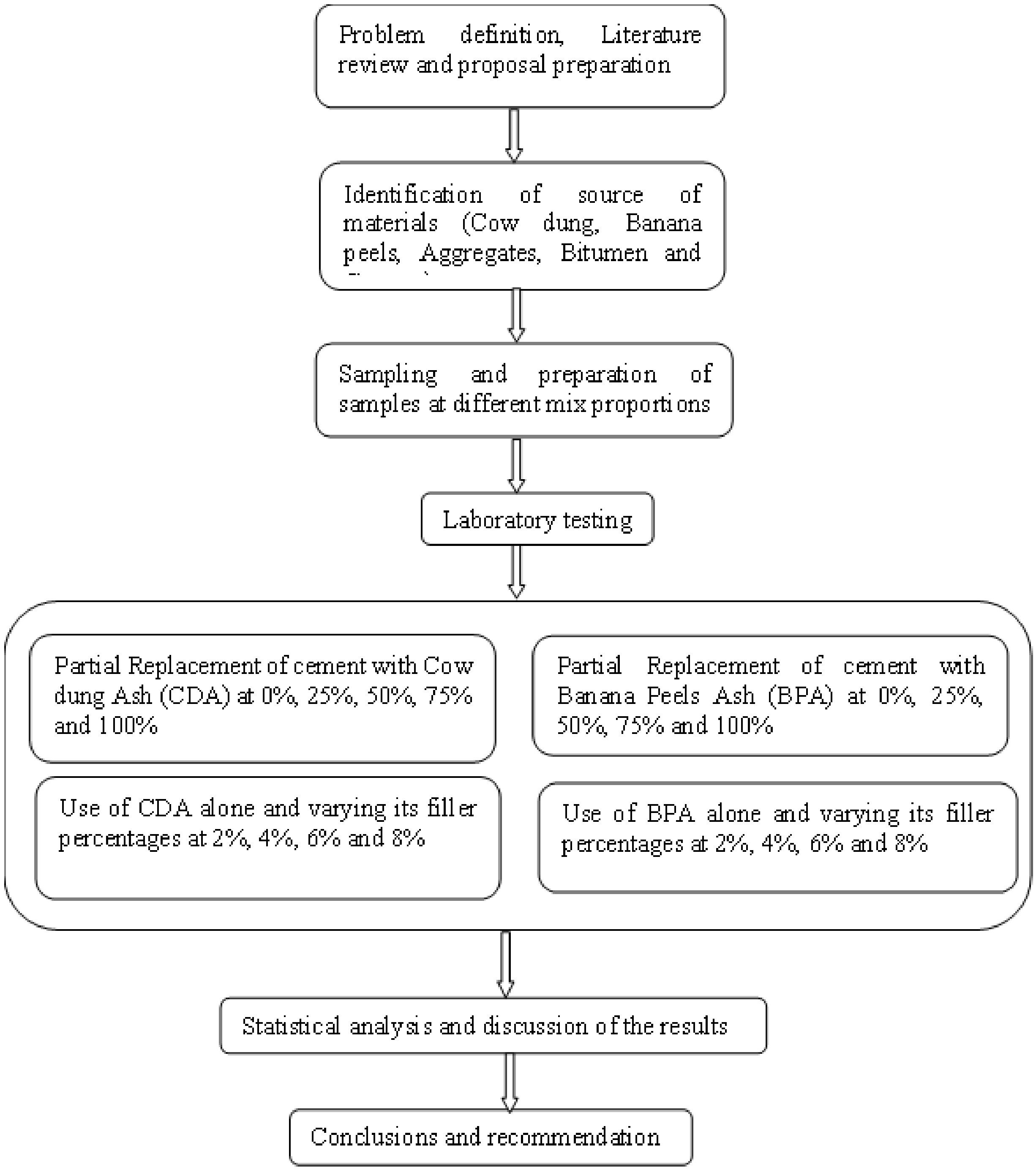

Figure 3.1: Research flow layout

3.2 Hot Mix Asphalt Materials

3.2.1 Aggregates

Aggregates were obtained from Mutu quarry in Kole which was a secondary quarry being used by UNRA for the construction of Apac-Lira-Puranga Road. The aggregates used were crushed in the sizes of 10 – 20 mm, 6 – 10 mm,3 – 6 mm and 0 - 3 mm. Samples for this research were taken from a hot bin where aggregates were heated up prior to mixing with bitumen. This helps to ensure proper bonding of aggregates with bitumen and also expel any moisture within the aggregates. The hot bin samples were then transported from the quarry to the laboratory in well labelled metallic drums. Prior to mixing, these aggregates were heated again and mixed with heated bitumen to a temperature of 150 - 170 ^{o}C. The prepared aggregated were contained in trays according to their sizes specified here and schematized in Figure 3.2.

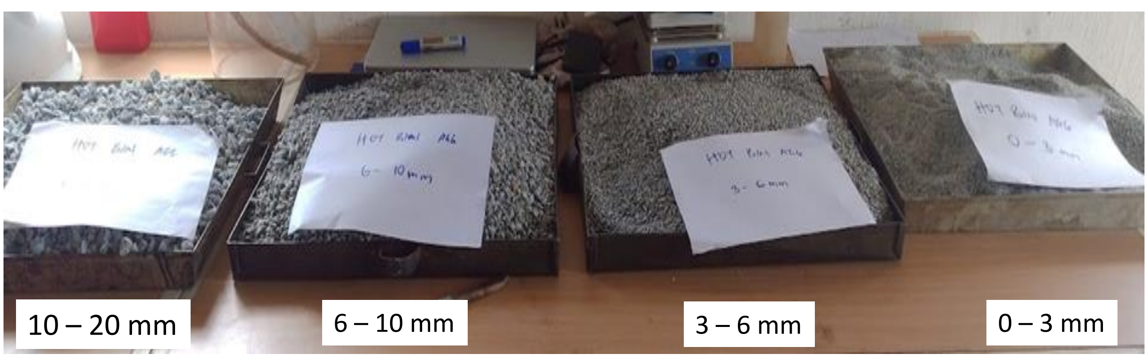

Figure 3.2: Hot bin aggregates contained in the trays as per their sizes.

3.2.2 Bitumen

Bitumen of 50/70 penetration grade was obtained from a local supplier Gulsan, a company contracted by UNRA to construct Apac-Lira-Puranga Road project. The supplier obtained bitumen from Kingdom of Bahrain, Middle East. A sample of 20 kg of bitumen was taken from the drum to carry out research and transported to the laboratory in tins. The bitumen was heated in the oven up to about 170 ^{o}C prior to testing and mixing as described in the following sections.

3.2.3 Filler Materials

a) Cement

The research utilised cement as a conventional filler in Hot Mix Asphalt (HMA). The Cement used was a grade 42.5 N ordinary Portland cement from Hima Cement factory. The cement was procured from a local supplier in bagged form and subsequently transported to the laboratory. To prevent moisture absorption, the cement bag was placed on an elevated platform, minimizing the risk of cement clumping due to its hygroscopic nature.

b) Cow Dung Ash (CDA) Preparation Procedure

The fresh cow dung of cows that feed purely on grass was collected from local farms in Kyeizooba in Bushenyi District, western Uganda. It was sun dried for 17 days on tarpaulin to avoid contamination. It was incinerated at 500 ^{o}C, then removed and allowed to cool within an open metallic wheelbarrow before sieving it through a sieve of 0.075 mm to obtain cow dung ash. CDA was greyish in colour. The sieved CDA was stored in airtight bags and placed in well labelled transparent buckets for easy identification. The procedures are schematized in Figure 3.3.

Figure 3.3: (a) Drying of cow dung, (b) Incinerator burning chamber, and (c) Incinerated cow dung ash

c) Banana Peels Ash (BPA) Preparation Procedure

The banana peels were collected from a banana factory in Bushenyi. The peels were then sun dried for 15 days on tarpaulin to avoid foreign materials contamination. The peels were incinerated, then removed and allowed to cool before sieving them through sieve 0.075 mm to obtain the Banana Peels Ash which appeared dark grey in colour. The preparation stages are illustrated in Figure 3.4. The sieved BPA was stored in airtight bags and placed in a well labelled transparent buckets for easy identification.

Figure 3.4: (a) Drying of banana peels, (b) Banana peels during incineration in the chamber, and (c) Sieving of cooled BPA using 0.075 mm diameter sieve

3.3 Material Characterisation

Different tests were carried out to determine the physical and chemical properties of the obtained materials according to ASTM, AASHTO, BS, Asphalt Institute standards.

3.3.1 Aggregates

a) Physical Properties Testing of Aggregates

Laboratory tests were conducted to ascertain the physical characteristics of the aggregates. according to the different available standards and to check for their suitability using Uganda MoWT General Specification 2005 for roads and bridges (Bagonza, 2005). Evaluation of aggregates was carried out to confirm their suitability for layer or whether they conformed to the standards. Physical tests carried out included specific gravity of aggregates, water absorption, aggregate crushing value and impact value of aggregates, ten percent fines value, sand equivalent, plasticity index, flakiness and soundness test, stripping test and grading.

b) Mechanical Strength Testing

The Tests are important because they predict the strength performance of the HMA. The Strength tests were carried out on the aggregates of sizes 10 – 20 mm. The tests that were carried out included Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Ten percent fines (TFV), and Los Angeles Abrasion Value (LAA) according to the standards as highlighted in Table 3.1. ACV and TFV are the quantity of aggregate resistance to gradually applied compressive load. In HMA, these tests are used to forecast the crushing load of the wheel loads onto aggregates. The test was done on fraction of 10 – 14 mm according to BS 812 part 110:1990.

The LAA test quantifies the deterioration of aggregates by subjecting them to a rotating drum along with steel spheres. As the drum revolves the aggregates are charged and disintegrate under the impact of spheres and other aggregates. The lower the value, the tougher the aggregates under abrasive loads and forces.

Table 3.1: Test Standards of aggregates strength properties

S/N	Test	Test Method
1	Aggregate Crushing Value (ACV)	BS 812: Part 110:1990
2	Aggregate Impact Value (AIV)	BS 812: Part, 112
3	Ten Percent Fines Value (TFV) Dry Wet	BS 812: Part, 111:1990
4	Loss Angeles abrasion test	

c) Flakiness Index Testing

Flakiness index assesses the geometric shape of aggregates, and it affects parking of aggregates because of their large surface area as compared to volume. Flaky aggregates are weak and crash easily and result into lower workability of mixture.

The test was carried out on aggregates size of 6.3 mm and above. This was done in accordance with the BS 812: section 105.1:1989. The individual aggregate fraction of sizes greater than 6.3 mm were mixed and used in this test.

d) Specific Gravity and Water Absorption Testing

Specific gravity is an important test to predict strength properties of aggregates in that the higher the specific gravity, the higher the strength and vice versa. In HMA, specific gravity is very important in the calculation of the volumetric properties of the mix. The different Specific gravity was determined on all fractions of the aggregates according to ASTM C128.

This describes the percentage increase in weight between dry aggregates and saturated aggregates. An increase in absorption leads to a decrease in the strength of aggregates.

Water absorption was also determined for different fractions of aggregates according to ASTM C128.

e) Soundness Test

This is a test carried out to determine the material disintegration under weathering conditions and in a particular freeze thaw cycle. The test utilised the use of sodium sulphate according to AASTHO T104.

f) Stripping Test

The stripping test was conducted following the guidelines outlined in AASHTO T-182.

g) Particle Size Analysis of the Aggregates

Grading was first carried out on each size of aggregates using the sieves described under Table 4202\2 of General Condition of Contract for Uganda. Grading was carried out in accordance with BS 1377 Part2:1990. The various grading sieves used for AC14 are as shown in Table 3.2.

Table 3.2: Sieve sizes and grading limits for aggregates

Sieve size (mm)	Asphalt concrete continuously graded (for AC14)
20	100
14	85 – 100
10	72 – 94
5	52 – 72
2.36	37 – 55
1.18	26 – 41
0.600	16 – 28
0.300	12 – 20
0.150	8 – 15
0.075	4 – 10
Aggregate	94.5 %
Bitumen content	5.5 %

Source: Uganda's MoWT General specification, 2005

Grading is very important in the performance of the mixes. Densely graded aggregates provide high frictional resistance, greater area of load transfer and maximum density that results into high stability of the final mix. In order to achieve a densely graded mix with high density, combined grading was done using trial and error method to ensure the grading is almost in middle of the envelope/target grading. However, maximum density gradation gives insufficient voids in the aggregates for the adequate binder to produce the required film thickness for maximum durability without bleeding. The target gradation was deviated from the maximum density curve especially on sieve 2.36 mm.

Furthermore, a gradation that closely aligns with the maximum density curve results in fewer voids within the mineral aggregates, consequently diminishing the mix's durability. Conversely, as the target gradation deviates from the maximum density curve, the voids in the mineral aggregate increase.

The individual fraction gradation was combined using a trial-and-error method that yielded different percentages by mass of the fraction to be combined to produce a perfect gradation within the gradation limit as per MoWT general specification for roads and bridges.

Different gradings were also obtained depending on the percentages of filler (2 %,4 % ,6 % and 8 %) and the mass per fractions were recorded. These different percentage by mass was then used to come up with the respective grading curve for different filler percentage.

h) Plasticity Index (PI) Testing

Plasticity Index is the range over which the material is plastic, and it is carried out on materials finer than 0.425 mm. It is the difference between liquid limit and plastic limit. PI affects the performance of HMA, and it is therefore recommended that materials to be used in HMA should have PI of less than 4%. The materials were first combined in accordance with the proportions of each percentage filler and then sieved through sieve 0.425mm. The test was conducted in accordance with BS 1377-Part 2:1990 as shown in Figure 3.5.

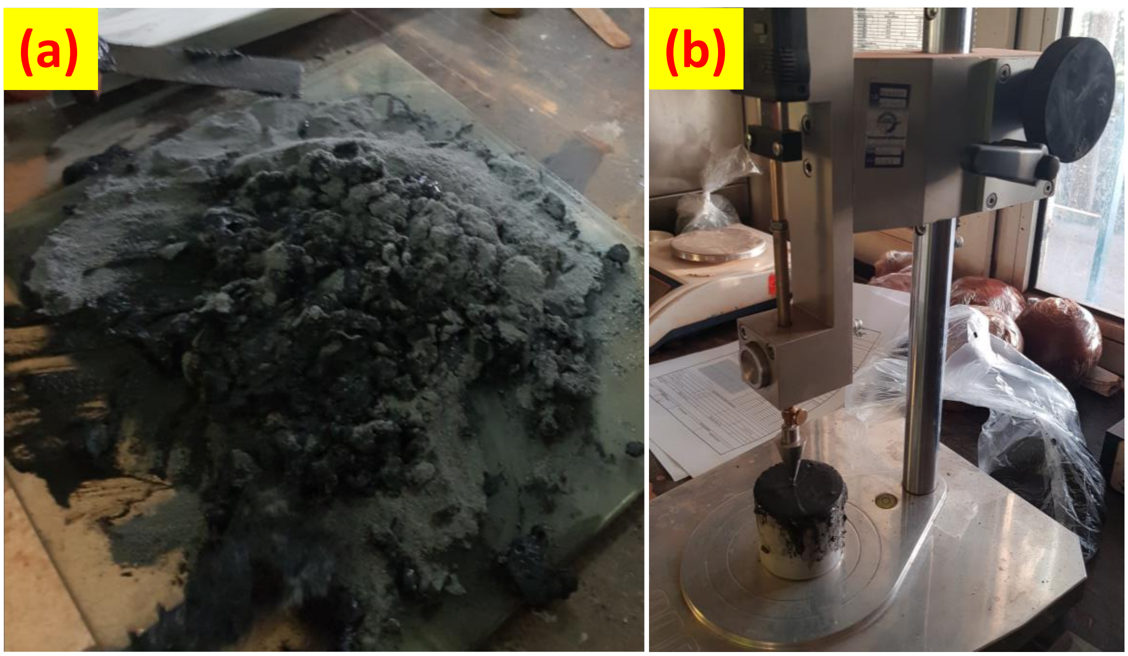

Figure 1.5: (a) Mixing of the filler material and (b) Plasticity index testing

3.3.2 Bitumen

Bitumen of grade 50/70 used in this work was classified according to MoWT general specification for road and bridges. The major binder selection tests were done on bitumen in accordance with various standards highlighted in Table 3.3 as also described thereafter.

Table 3.3: Standard Tests on Bitumen

Test	Standards
Penetration at 25 ^{o}C	BS EN 1426
Softening Point	BS EN 1427
Flash Point	BS EN ISO 2592
Fire Point	BS EN 1SO 2592
Ductility	BS EN 13589:2018
Specific Gravity	ASTM D70
Solubility in Trichloroethylene	ASTM D2042
Water Content	EN 12607-1

a) Penetration Test

The penetration test evaluates the hardness of the binder. This test is good for selection of a binder for a given region. A higher penetration represents a softer binder, and a lower penetration represents a harder binder.

b) Softening Point

This is a consistency test that shows temperature a certain viscosity is attained by the bitumen. It is important in binder selection because the hotter regions require a high softening point unlike the colder regions. The method employed to ascertain the softening point adhered to the specifications outlined in BS EN 1427.

c) Flash and Fire Point

This represents the maximum temperature bitumen can be handled and stored safely. Bitumen is an organic compound and when heated to a certain temperature, volatile gases escape, this point is referred to as flash point. The procedure followed was according to BS EN ISO 2592.

d) Solubility

This is a purity test. A sample was immersed in trichloroethylene to dissolve. The bitumen dissolved and the insoluble part was filtered out and weighed according to ASTM D2042.

3.3.3 Filler Materials

The prepared filler materials of cement, cow dung ash and banana peels ash were held in trays prior to testing as shown in Figure 3.6.

Figure 3.6: Filler materials (Cement, Banana peels ash (BPA) and Cow dung ash (CDA))

a) Cement

The physical test that was carried out on cement was specific gravity since specific gravity helps in determining the volumetric properties of HMA. The specific gravity was carried out as per ASHTO T-133.

b) Cow Dung Ash

A sample of 500 g of CDA was taken to Hima cement laboratory for chemical analysis to determine and compare its properties with cement. Cement being an active filler contains silica, alumna, ferrous and calcium oxide which are the active cementitious ingredients. The tests were carried out according to US EAS 148-2:2017. Physical properties of specific gravity and plasticity index were also determined according to ASHTO T-133 and BS 1377-Part 2:1990 standards respectively.

c) Banana Peels Ash

A sample weighing 500 g of BPA was taken to Hima cement laboratory for chemical analysis to establish and compare its properties with cement. The tests were carried out according to US EAS 148-2:2017. Also, physical properties including specific gravity and plasticity index were evaluated according to ASHTO T-133 and BS 1377-Part 2:1990 standards respectively.

3.4 Marshal Mix Design

3.4.1 Conventional Mix

A conventional mix with a filler percentage of 4 % cement was chosen because it gave the perfect gradation within the limit of Table 4202/2 of MoWT General Specifications for

Roads and Bridges, 2005 (Bagonza, 2005) as shown in Figure 3.7. A marshal mix design was used to ascertain the volumetric properties of the resulting mix.

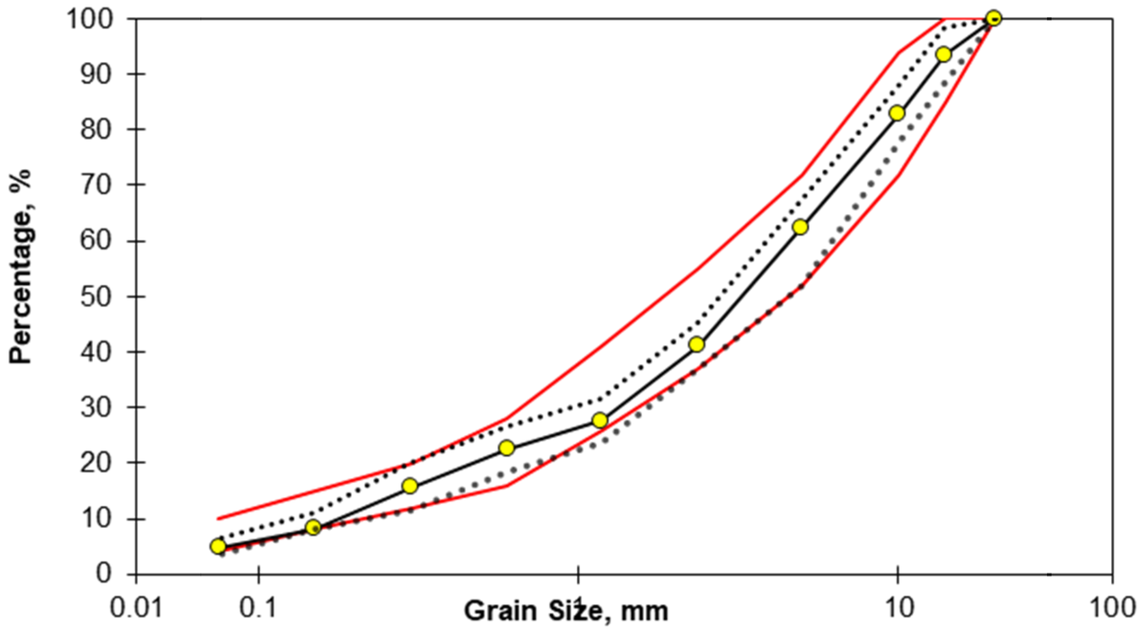

Figure 3.7: Gradation of conventional mix

The proportion by mass of different fractions of aggregates was determined and is as shown in Table 3.4. This gave a Job Mix Formula for the conventional mix in which properties of the other mix would be compared.

Table 3.4: Proportion of materials used

Sieve Size (mm)	**10 - 20**	**6 - 10**	**3 - 6**	**0 – 3**	**Filler (cement)**
Proportion (%)	24	16	20	36	4

a) Marshall Specimen Preparation

Aggregates and filler materials were mixed according to the proportion in Table 3.4 as dry mix design by weighing 1200 g of aggregates and filler according to their different determined specific gravities. The dry mix of aggregates and filler were heated at a temperature of 150 to 170 ^{o}C to expel water and improve on aggregate to bitumen bond. The Bitumen was heated to 150 to 165 ^{o} C. Varied Bitumen contents of 4 %, 4.5 %, 5.0 %, 5.5 %, 6.0 %, 6.5 % were considered and added to the heated aggregates and filler and then mixed thoroughly to get homogenous mixture. For each bitumen content, triplicate samples were prepared, and the mixed samples are as shown in the Figure 3.8.

Figure 3.8: (a) Dry aggregate and cement mix and (b) Aggregate, cement and bitumen mixed materials

The mixed aggregate, cement and bitumen materials were placed in Marshall mould of 100 mm diameter by approximately 63.5 mm and compacted with a 4.54 kg rammer falling at a height of 45.7 cm for 75 blows on each side and three specimens were compacted for every bitumen content. Compacted specimens were allowed to cool overnight and extracted using an extruder. The procedure according to MS-2 (2014) was then repeated for all other bitumen contents. The prepared compacted samples are as shown in Figure 3.9.

Figure 3.9: Compacted samples prepared using the conventional filler (cement)

3.4.2 Partial Replacement Mix

Upon establishing the optimum bitumen content using the conventional filler of 4 % cement, the green filler alternatives of cow dung ash and banana peels ash were used to substitute the cement filler in varied proportions. Cow dung ash contents included 0 %, 25 %, 50 %, 75 % and 100 % of the 4 % cement. For the banana peels ash, it entailed 0 %, 25 %, 50 %, 75 % and 100 % of the 4 % cement. These varied proportions are referred to as partial replacement in this study. In brief, partial replacement meant that 4% of the cement filler was replaced by either CDA or BPA.

With the optimal bitumen content determined as 5.4%, partial replacement samples were prepared according to specified compaction procedures described in 3.4.1(a).

3.4.3 Full Replacement Mix

In here, the cement filler material was fully replaced with either cow dung ash or banana peels ash at varied filler percentages of 2 %, 4 %, 6 % and 8 %. These proportions are referred to as full replacement in this study. Full replacement implies that either CDA or BPA was solely used as a filler in this scenario.

For each filler percentage, the full replacement samples were prepared as shown in Figure 3.10 by compaction following the procedures described above. To establish the optimum bitumen content, triplicate samples were prepared at different bitumen contents as in Table 3.5 for BPA filler (as shown in Figure 3.8) and Table 3.6 for CDA filler. Based on the voids content, bulk specific gravity and stability analysis, the optimum bitumen content was obtained and further validated at that specific value.

Table 3.5: Bitumen contents for BPA

	Filler (%)			
	2	**4**	**6**	**8**
	4.0	4.5	6.0	7.0
	4.5	5.0	6.5	7.5
Bitumen	5.0	5.5	7.0	8.0
content (%)	5.5	6.0	7.5	9.0
	6.0	6.5	8.0	
	6.5	7.0		

Figure 3.10: (A) 6 % BPA mixed samples and (B) Compacted samples of 6% and 8 % BPA

Table 3.6: Bitumen contents for CDA

	Filler (%)			
	2	4	6	8
Bitumen content (%)	4.0	4.5	6.5	7.5
	4.5	5.0	7.0	8.0
	5.0	5.5	7.5	9.0
	5.5	6.0	8.0	9.5
	6.0	6.5	8.5	
	6.5			

3.5 Determination of Marshal and Volumetric Properties of Specimens

3.5.1 Bulk Specific Gravity

Bulk specific gravity is used in determination of voids in the mix, and it should not be greater than the theoretical maximum specific gravity. Bulk specific gravity testing was conducted on every compacted specimen in accordance with AASHTO T-166. Compacted specimens were left in the moulds overnight to cool. After removing the compacted specimens from the moulds, they were rubbed with a piece of dry cloth to remove any loose material and then its weight in air (A) obtained as illustrated in Figure 3.11. Each compacted specimen was further weighed under water and its weight recorded (C). After removing from water, a dry woollen piece of cloth was used to remove any surface water on the specimen and again its weight in air taken (B). The bulk specific gravity (Gmb) of each compacted specimen was calculated using the expression in Equation 3.1.

Bulk specific gravity (Gmb) = $\frac{A}{B-C}$.. Equation 3.1

Where A is the mass of dry specimen in air, B is the Saturated Surface Dry mass (SSD) of the specimen and C is the submerged mass of the specimen.

Figure 3.11: Weighing of the prepared compacted specimens

3.5.2 Maximum Theoretical Specific Gravity of Loose Mix (Gmm)

Maximum theoretical specific gravity of asphalt mixed samples is very vital in evaluating the volumetric properties of the HMA. It should be greater than bulk specific gravity of the mixed sample but less than the bulk specific gravities of total aggregate **(**Gsb), apparent bulk specific gravity (Gsa), and effective specific gravity (Gse). It is used together with bulk specific gravity to determine voids in the mix. Two samples at every bitumen content were prepared and loosen up in the process of cooling as shown in Figure 3.12. Maximum specific gravity of mixes for every bitumen content was determined in accordance with AASHTO T-209 using Equation 3.2.

$$\text{Gmm} = \frac{A}{A+B-C} \quad \text{.......... Equation 3.2}$$

Where A is the weight of dry mixed sample in air in grams, B is the weight of pycnometer filled with water at required test temperature in grams and C is the weight of pycnometer filled with mixed sample and water at the test ambient conditions.

Figure 3.12: Mixed samples for GMM test

3.5.3 Voids in the Mix (V_a)

The percentage of air voids in compacted specimen (V_a) is the ratio of the difference between the maximum theoretical specific gravity of the loose asphalt mixtures (G_{mm}) and bulk density of each compacted specimen (Gmb) to the maximum theoretical specific gravity expressed as a percentage. It is obtained using Equation 3.3.

$$V_a = \left(\frac{Gmm - Gmb}{Gmm}\right) * 100 \quad \text{……………………………………………Equation 3.3}$$

3.5.4 Voids in Mineral Aggregate (VMA)

The percent voids in mineral aggregates (VMA) is the percentage of void spaces between the granular particles in the compacted sample, including the air voids and the volume occupied by the effective asphalt content. VMA is related to nominal size of the aggregates used and is given by the Equation 3.4

$$\text{VMA} = 100 - \frac{Gmb - P_s}{G_{sb}} \text{...Equation 3.4}$$

Where G_{sb} is the bulk specific gravity for total aggregates, P_s is the percent of aggregates by total weight of mixture.

3.5.5 Voids Filled with Bitumen (VFB)

The percent of air voids in mineral aggregates filled with bitumen (VFB) is the ratio (expressed as a percentage) between the volume of the air voids within the coated particles to the total volume of the mixture and is given by Equation 3.5.

$$\text{VFB} = \frac{VMA - Va}{VMA} \text{ x } 100 \text{...Equation 3.5}$$

3.5.6 Measurement of Stability and Flow

The specimen was placed in a test assembly as shown in Figure 3.13 and loaded at a constant deformation rate of 51 mm/min while monitoring the load and deformation readings. The maximum force was recorded as the stability of the compacted specimen (kN) whereas the corresponding deformation was taken as the flow (mm). Marshall stability index was calculated from the ratio of stability of the compacted specimen to its flow.

Figure 3.13: Marshal stability and flow testing

3.5.7 Determination of Optimum Bitumen Content (OBC)

Optimum bitumen content was obtained from method 2 of averages in accordance to the National Asphalt Institute Association standard. A graph of percentage voids against bitumen content was plotted and bitumen content corresponding to 4 % voids recorded. Another graph of bulk specific density against bitumen contents was plotted and the bitumen content corresponding with maximum density recorded. Further, a graph of stability against bitumen content was plotted and bitumen content equivalent to maximum stability then recorded. The averages of the recorded bitumen content was taken as the Optimum Bitumen content (OBC).

3.5.8 Determination of Indirect Tensile Strength (ITS)

Indirect Tensile Strength testing measures the resistance of HMA to tensile cracking forces. It is determined through subjecting a cylindrical sample of HMA to compressive loads along the diametrical plane. The ratio of unconditioned tensile strength (dry) and conditioned tensile strength (dry) determines the susceptibility of HMA to moisture. This is a durability test to determine the resistance of asphalt mixes to induced moisture damages. It was carried out in accordance with AASHTO T 283. The test was held on samples at optimum bitumen content of 5.4 % for the conventional cement filler. Moreso, for the CDA filler, the ITS was evaluated at 5.4 %, 5.8 %, 7.3 % and 8.3 % optimum bitumen contents corresponding to 2 %, 4 %, 6 % and 8 %. Meanwhile for the BPA filler, ITS was obtained at 5.9 %, 6.3 %, 6.9 % and 7.9 % optimum bitumen contents corresponding to 2 %, 4 %, 6 % and 8 % BPA. The ITS was calculated using Equation 3.6.

$$ITS = \frac{2000\,P}{\pi D T} \quad \text{Equation 3.6}$$

Where P is the load at failure (N), D is the diameter of the specimen (mm) and T is the thickness/height of the specimen (mm).

3.6 Summary

In this section, preliminary tests on the constituent materials; aggregates, cow dung ash, banana peels ash and bitumen were conducted to assess their suitability in preparation of the hot mix asphalt. The tests performed included particle size distribution, aggregate crushing value, Loss Angeles abrasion value, specific gravity, water absorption, plasticity index, chemical analysis and other physical tests in accordance with the AASHTO, ASTM, and BS test standards.

Marshal mix design procedures were used in preparation of all the test specimens using the conventional cement filler of 4 % at various bitumen contents to establish the optimum bitumen content. The obtained optimum bitumen content was then used with the organic fillers materials of either cow dung ash or banana peels ash at varied proportions of 25 %, 50%, 75%, 100 % based on the partial replacement approach. In addition, full conventional cement filler replacement was assessed at filler contents of 2 %, 4 %, 6%, 8 % for either cow dung ash or banana peels ash. In all the investigated organic filler replacement scenarios, marshal and volumetric properties were evaluated to ascertain their potential utilization in the hot mix asphalt used for construction of low traffic roads (< $1x10^6$ ESAs).

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CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter covers the results that were obtained during the research. All the data analysis was performed using Excel spreadsheets and statistical tests by R software as presented in the subsequent sections.

4.1 Material Characterisation

4.1.1 Physical-Mechanical Properties of Aggregates

The laboratory tests were carried out on aggregates to determine their physical-mechanical properties according to the different available standards and to check for its suitability and compliance with the MoWT general specification 2005 for roads and bridges (Bagonza, 2005). Some of the physical and mechanical test results are summarised in Table 4-1.

The strength parameters of Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Ten Percent Fines Value (TFV), Flakiness Index (FI) and Loss Angeles abrasion value (LAAV) were conducted. These are important in that they predict the performance of aggregates during mixing, compaction and use during trafficking. Aggregates that have low strength disintegrate during compaction hence disorganising the gradation that affects the performance of Hot Mix Asphalt (HMA). The aggregates test results of this study lied within the requirements as per the Uganda MoWT General Specification 2005 for Roads and Bridges as indicated in the Table 4.1.

The abrasion test is important to determine the abrasion resistance of aggregates to exposed traffic. The test carried out passes the requirement in road note 19 (UK Department for International Development, 2002). Therefore, the aggregates chosen would perform better under traffic.

Test on water absorption is important because it affects bitumen affinity to aggregates and also affects performance of HMA. Highly absorptive aggregates are weak and can cause cracking and lose of aggregates of the HMA during use. Test carried out showed that aggregates chosen were low absorptive type giving a high affinity to bitumen.

4.1.2 Mechanical Strength Test

The tests are important because they predict the strength performance of the HMA. The Strength tests were carried on the aggregates of sizes 10 – 20 mm. The tests that were carried out included Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV), Ten percent fines (TFV), and Loss Angels Abrasion Value (LAAV) and the results are shown in Table 4.1Table 3.1**.** The strength properties were done on the largest group of aggregates of 10 – 20 mm.

ACV and TFV are the measure of aggregate resistance to gradually applied compressive load. In HMA, these tests would be used to simulate the crushing load of the wheel loads onto aggregates.

LAAV tests is a measure of aggregate degradation when placed in a rotating drum with steel spheres. As the drum rotates the aggregates are charged and disintegrates under the impact of spheres and other aggregates. The lower the value the tougher the aggregates under abrasive loads and forces.

4.1.3 Flakiness index

Flakiness index is a measure of the shape of aggregates and flaky aggregates affects parking of aggregates because of they have a large surface area compared to the volume they occupied. Flaky aggregates are weak and crash easily and result into lower workability of mixture.

4.1.4 Specific Gravity and Water absorption

The specific gravity is an important test because it predicts the strength properties of the aggregates in that the higher the specific gravity, the higher the strength and vice versa. In HMA, specific gravity is very important in the calculation of the volumetric properties of the mix. The different Specific gravities of the aggregate fractions were determined and summary of the results are tabulated in Table 4.1.

The higher the water absorption the lower the strength of aggregates and vice versa. According to MoWT General Specifications for Roads and Bridges 2005 (Bagonza, 2005) aggregates should not absorb more that 2 % of water by mass as highlighted in Table 4.1.

4.1.5 Soundness Test

This is a test carried out to determine the material disintegration under weathering conditions and in a particular freeze thaw cycle. The MoWT General Specifications for Roads and Bridges requires soundness to be less than 12 %. The study findings recorded an average of 1.5 % which implied that the aggregates had a low susceptibility to disintegration.

Table 4.1: Physical and Chemical tests on aggregates

Sieve Size	Test Parameters	Average Results	Standards	Specifications*
10 -14 mm	ACV (%)	23.6	BS 812: Part 110:1990	Max 30
	AIV (%)	12.7	BS 812: Part, 112	Max 25
	TFV Dry (kN)	183.5	BS 812: Part, 111:1990	Min 110
	TFV Wet/soaked (kN)	179.5		
	TFV Ratio (%)	98		Min 75
	FI (%)	12.5	BS 812:103:1:1985	
	LAAV (%)	16.5		Max 50
	SSS (%)	1.5	AASHTO T-104	Max 12
	Stripping Test (%)	96.5	AASHTO T-182	Min 95
10 - 20 mm	Bulk Specific Gravity - Oven (g/cm^3)	2.667	BS 812 Part 2 :1995	
	Bulk Specific Gravity SSD (g/cm^3)	2.679		
	Apparent specific gravity(g/cm^3)	2.699		
	Water Absorption (%)	0.442		Max 2 %
6 - 10 mm	Bulk Specific Gravity-Oven (g/cm^3)	2.657		
	Bulk Specific Gravity SSD (g/cm^3)	2.672		

	Apparent specific gravity (g/cm^3)	2.698		
	Water Absorption (%)	0.562		Max 2 %
3 - 6 mm	Bulk Specific Gravity - Oven (g/cm^3)	2.655		
	Bulk Specific Gravity SSD (g/cm^3)	2.674		
	Apparent specific gravity (g/cm^3)	2.708		
	Water Absorption (%)	0.743	ASTM C128	Max 2 %
0 - 3mm	Bulk Specific Gravity - Oven (g/cm^3)	2.688		
	Bulk Specific Gravity SSD (g/cm^3)	2.709		
	Apparent specific gravity (g/cm^3)	2.745		
	Water Absorption (%)	0.783		Max 2 %

*Uganda MoWT General Specification 2005 for roads and bridges

4.1.6 Particle size analysis of the aggregates

Grading was first carried out on each size of aggregates using the sieves described under Table 4202\2 of General Condition of Contract for Uganda and results obtained for each size of aggregates are summarized in the Table 4.2.

Table 4.2: Grading for different fractions of aggregates

Sieve size	10-20mm % Passing	6-10mm % Passing	3-6mm % Passing	0-3mm % Passing	Grading Envelope (%)
20	100	100	100	100	100-100
14	73.2	100	100	100	85-100
10	28.6	100	100	100	72-94
5	0.4	15.6	98.9	100	52-72
2.36	0.1	1.1	13.6	96.1	37-55
1.18	0.1	0.3	1.4	73.7	26-41
0.600	0.1	0.3	0.9	62.6	16-28
0.300	0.1	0.3	0.8	45.4	12-20
0.150	0.1	0.3	0.7	21.8	8-15
0.075	0.1	0.2	0.4	6.1	4-10

Combined grading was done using trial and error method to ensure the grading curve for each filler content (2 %,4 % ,6 % and 8 %) is almost in middle of the envelope/target grading. The proportions of achieving the envelope/target grading were obtained in the Job mix formula for different filler percentages and the mass per fractions as presented in Table 4.3. The different percentage by mass as summarized in Table 4.4 were used to come up with the respective grading curve for the different filler percentage as shown in Figure 4.1.

Table 4.3: Job mix formula for different filler percentages

Fraction	2% filler percentage combination by mass	4% filler percentage combination by mass	6% filler percentage combination by mass	8% filler percentage combination by mass
10 – 20 mm	26	24	25	26
6 – 10 mm	16	16	16	18
3 – 6 mm	12	20	15	16
0 – 3 mm	44	36	38	32
Filler (5 %)	2	4	6	8

Table 4.4: Combined Gradation of Aggregates and Filler

	Filler content (%)				
	2	**4**	**6**	**8**	
Sieve sizes	% Passing	% Passing	% Passing	% Passing	Grading Envelope (%)
20	100	100	100	100	100 - 100
14	93	93.6	93.3	93	85 - 100
10	81.4	82.9	82.2	81.4	72 - 94
5	60.5	62.4	61.4	58.7	52 - 72
2.36	45.7	41.2	44.4	40.9	37 - 55
1.18	30.8	27.7	30.9	29.1	26 - 41
0.600	24.5	22.5	25.5	24.5	16 - 28
0.300	16.1	15.6	18.2	18.4	12 - 20
0.150	7	8.2	10.4	11.7	8 - 15
0.075	3	4.9	6.9	8.8	4 - 10

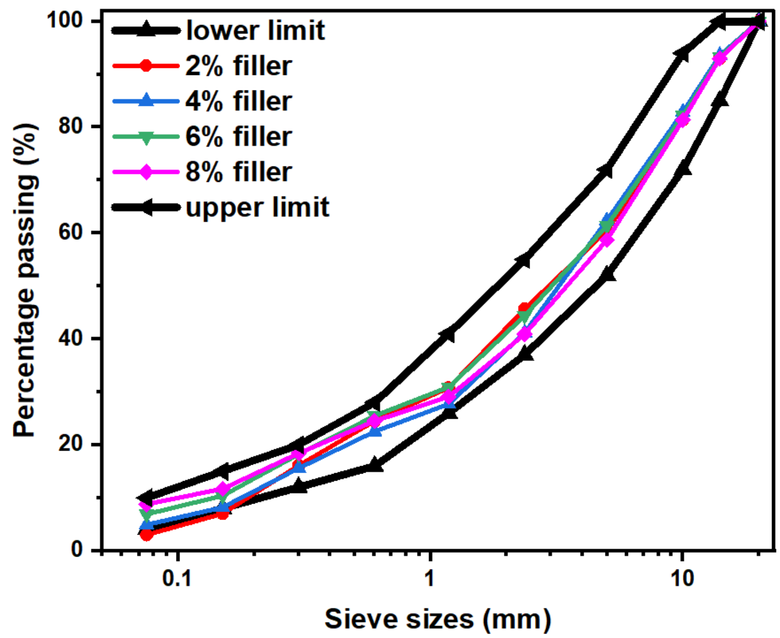

Figure 4.1: Combined gradation curves for the different filler percentages

4.1.7 Bitumen Properties

The bitumen obtained was graded using penetration as pen 50/70. The different properties test results obtained were entered in Table 4.5. This bitumen is suitable in this region of tropical climate since the softening point was above the highest temperature recorded in Uganda. Flash point is the maximum temperature in which bitumen can be safely handled and it's based on to determine the mixing temperature of the asphalt. The mixing temperature specified for 50/70 pen bitumen is between 135 – 160 ^{o}C.

Table 4.5: Bitumen test properties

Test	Average Result	Specifications: US EAS 982-1:2020 for pen Grade Bitumen 50/70
Penetration at 25^oC (mm)	67.2	50 - 70
Softening Point (^oC)	53.4	46 - 54
Flash Point (^oC)	294	Min 230
Fire Point (^oC)	309	-
Ductility (cm)	111.9	Min 100
Specific Gravity	1.030	-
Solubility in Trichloroethylene (%)	99.60	Min 99 %
Water Content (%)	0.06	Max 0.2
Stripping and coating (%)	95	Min 95 %

4.1.8 Fillers (Cement, CDA and BPA) Properties

Cement, Banana peels ash (BPA) and Cow dung Ash (CDA) were used as the filler materials and their properties tested, both chemical and physical tests as summarised in Table 4.6. From the Table 4.6, the difference in the specific gravities of the different fillers showed that the used organic fillers are light in weight compared to the active cement filler. This affects the overall bulk specific gravity of the mix. The resultant bulk specific gravity of the mix when using the organic fillers was lower than that when cement was used in the mix. That is to say, 3.059 g/cm^3 for cement compared to 2.258 g/cm^3 and 2.141 g/cm^3 for cow dung ash and banana peels ash respectively.

In terms of chemical composition, the lime content (CaO) for cement (63.7%) is higher than for both cow dung ash (44.44 %) and banana peels ash (3.47%). A higher CaO content in the filler material improves the hydration properties of the mix. Cow dung ash revealed a higher SiO_2 content (29.67 %) than cement (20.1%) and banana peels ash (19.60 %). A filler material with a higher SiO_2 forms dense microstructures within the asphalt mix which lowers the voids content, thus a higher strength (Al-Zarjawi, Mahdi and Abbas, 2020).

For physical properties, both CDA and BPA were non plastic. Meanwhile, from the chemical composition analysis, SiO_2, Al_2O_3 and CaO constituent the highest proportions in CDA and BPA. Based on these exhibited physical and chemical attributes, both CDA & BPA are potential alternatives for the replacement of cement in appropriate ratios.

Table 4.6: Physical and Chemical tests on fillers

	Fillers		
Test	**Cement[a]**	**CDA**	**BPA**
Specific gravity (g/cm^3)	3.059	2.258	2.141
Plasticity index (%)	Non plastic	Non plastic	Non plastic
Loss on ignition (%)	2.6	5.21	36.64
Chemical Composition (%)			
SiO_2	20.1	29.67	19.60
Al_2O_3	4.7	5.80	2.01
Fe_2O_3	3.5	6.96	1.15
CaO	63.7	44.44	3.47
MgO	0.7	6.96	8.08
SO_3	3.1	2.57	1.36

K_2O		2.45	45.18
Na_2O	0.51	0.52	0.62
P_2O_5		0.54	4.90
pH		5.95	10.25

[a](Fu *et al.*, 2017)

4.2 Marshal Mix Design

4.2.1 Conventional Mix

The measured properties of the conventional mix of 4 % cement filler are summarized in Table 4.7. These included the bulk specific gravity, maximum theoretical specific gravity, void in mineral aggregates, void in mix, void filled with bitumen, stability, Marshal flow and the stiffness index. From the Table 4.7 as well as Figure 4.2 (a), the bulk specific gravity increased from 2.314 g/cm^3 at 4 % bitumen content to 2.420 g/cm^3 at 6.5 % bitumen content. This increase was attributed to the more addition of the bitumen portion that filled the voids thus lowering the voids content in the mix (V_a) from 8.8 % at 4 % bitumen content to 1.8 % at 6.5 % bitumen content (John, Bangi and Lawrence, 2021). Maximum theoretical specific gravity of loose material reduced with increase in the bitumen content as noted within the Figure 4.2 (b). The maximum theoretical specific gravity relies on the specific gravities and composition of the individual constituents within the mix such as aggregates, filler and bitumen content. Thus, an increase in bitumen content amounts to a decrease in the rest of the constituents within the mix such as aggregates and filler with higher specific gravities (El Sayed, 2012).

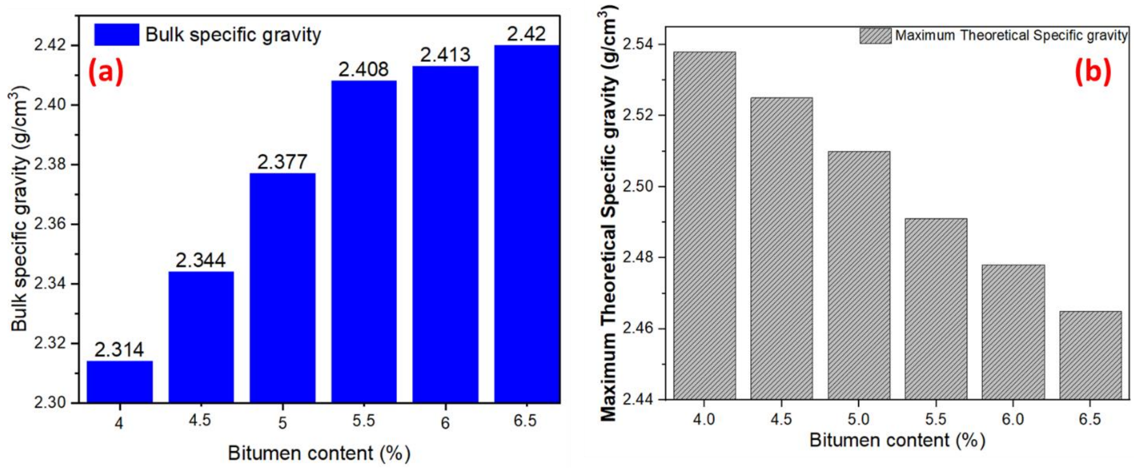

Figure 4.2: (a) Bulk specific gravity and (b) maximum theoretical specific gravity of the conventional mix

Meanwhile, the voids filled with bitumen content increased with further addition of the bitumen content, as shown in Figure 4.3 (a). In a study by Jeffry *et al.*(2016), it is suggested that a VFB value above 80 – 85 % results into an unstable asphalt mix. For the Voids in the Mineral Aggregate (VMA), an increase in the bitumen content resulted into a decline in the VMA, that is from 17.2 % VMA at 4 % bitumen content to 15.6 % VMA at 6.5 % as shown in Figure 4.3 (b). A high VMA is undesirable since it necessitates a higher amount of bitumen to lower the air voids within the mix, thus uneconomical (Sharma and Khan, 2017).

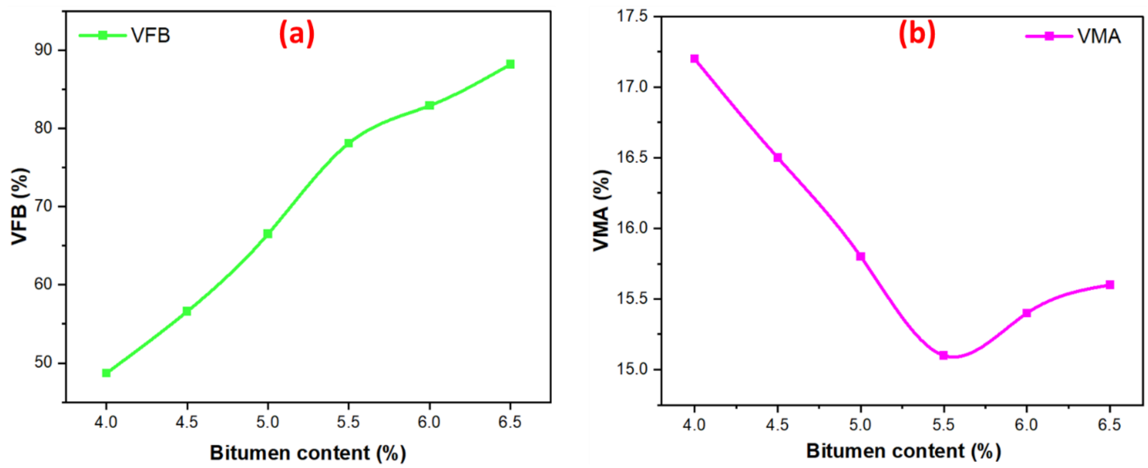

Figure 4.3: (a) Voids filled with bitumen (VFB) and (b) Voids in the Mineral Aggregate (VMA) of the conventional mix

Stability of the mix increased from 13.5 kN at 4 % bitumen content to a maximum of 16.1 kN at 5 % bitumen content after which further increase in bitumen content resulted in a decline of the stability up to 14.2 kN at 6.5 % bitumen content as shown in Figure 4.4 (a). A higher stability enhances the specimen's ability to withstand more deformation loads (Jaya *et al.*, 2014). This behaviour is due to a reduction in the airspaces initially which increases the density as well as the aggregate particle interlocking. With complete filling of the airspaces, additional bitumen content is surplus and increases the volume, thus a decline in density and subsequently the stability (Hossain, 2018).

In Figure 4.4 (b), Marshall flow increased with increase in the bitumen content from 2.5 mm at 4 % bitumen content to 4.2 mm at 6.5 % bitumen content which lied within the acceptable range of 2 - 4 mm (Emer T. Quezon, Fisseha Wagaw, 2018).

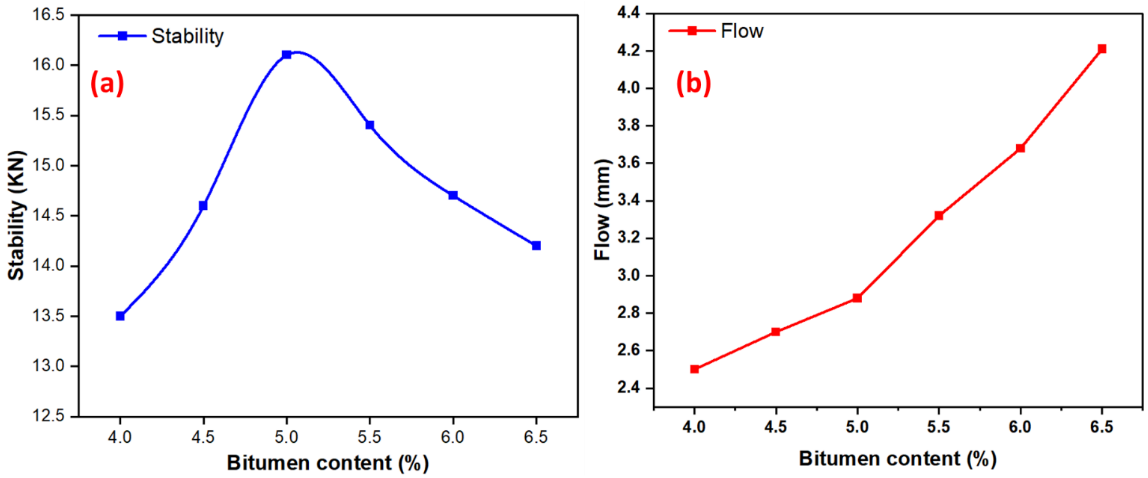

Figure 4.4: (a) Stability and (b) Flow of the conventional mix

Table 4.7: Test properties of the Conventional mix

Bitumen Content	4	4.5	5	5.5	6	6.5	Spec
Bulk Specific Gravity	2.310	2.342	2.377	2.411	2.415	2.420	
	2.314	2.345	2.376	2.409	2.414	2.420	
	2.318	2.345	2.379	2.405	2.409	2.419	
	2.314	**2.344**	**2.377**	**2.408**	**2.413**	**2.420**	**N/A**
Max Theoretical Specific Gravity	2.538	2.525	2.51	2.491	2.478	2.465	
Void in mineral aggregates (VMA)	17.3	16.6	15.8	15.1	15.4	15.7	
	17.2	16.5	15.8	15.1	15.4	15.6	
	17.0	16.5	15.7	15.3	15.6	15.7	
	17.2	**16.5**	**15.8**	**15.1**	**15.4**	**15.6**	**Min 15**
Void In Mix (VIM)	9.0	7.3	5.3	3.2	2.5	1.8	
	8.8	7.1	5.3	3.3	2.6	1.8	
	8.7	7.1	5.2	3.4	2.8	1.9	
	8.8	**7.2**	**5.3**	**3.3**	**2.6**	**1.8**	**3-5**
Void filled with Bit (VFB)	48.2	56.3	66.5	78.6	83.5	88.2	
	48.7	56.8	66.4	78.3	83.2	88.4	
	49.1	56.7	66.7	77.4	82.1	88.0	
	48.7	**56.6**	**66.5**	**78.1**	**82.9**	**88.2**	**65-80**
Stability (KN)	13.3	14.5	16.1	15.5	14.3	14.1	
	13.5	14.0	15.8	15.4	14.6	14.2	
	13.6	15.1	16.3	15.2	15.2	14.3	
	13.5	**14.6**	**16.1**	**15.4**	**14.7**	**14.2**	**6-18KN**
Marshall Flow	2.43	2.74	2.986	3.24	3.58	4.21	
	2.48	2.69	2.81	3.35	3.77	4.05	
	2.59	2.66	2.85	3.38	3.69	4.38	
	2.5	**2.7**	**2.9**	**3.3**	**3.7**	**4.2**	**2 - 4**
Stiffiness Index	**5.4**	**5.4**	**5.6**	**4.6**	**4.0**	**3.4**	

4.2.2 Determination of the Optimum Bitumen Content

The optimum bitumen content was obtained as an average value of the bitumen contents from the plots as graphically illustrated in the Figure 4.5 (a) - (c) based on the bulk specific gravity, voids in the mix and the stability. From the analysis, the optimum bitumen content was calculated as 5.4 %.

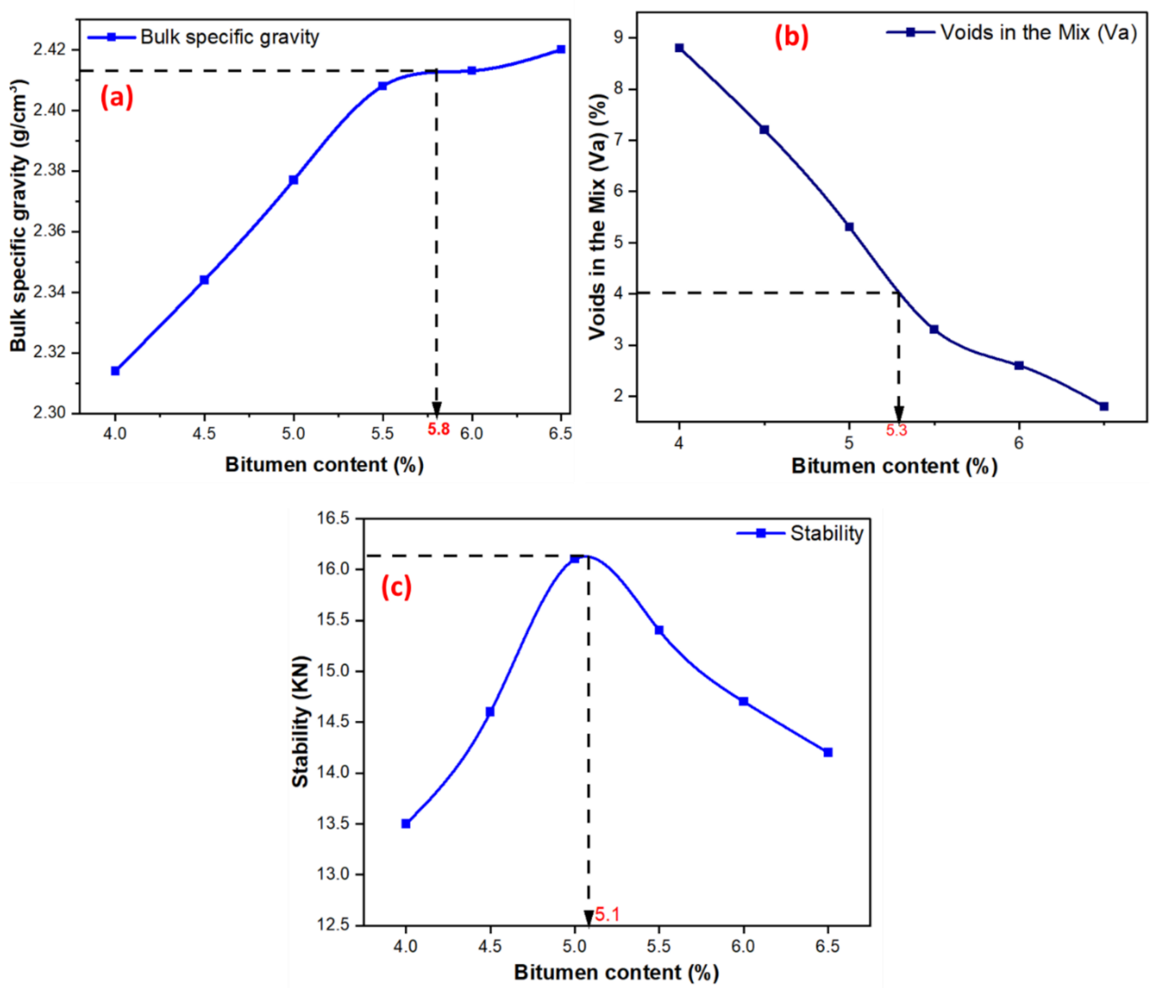

Figure 4.5: Optimum bitumen content graphical analysis based on (a) Bulk specific gravity, (b) Voids in the mix and (c) Stability.

4.3 Conventional Mix Properties at Optimum Bitumen Content of 5.4 %

From the graphical determination of the optimum bitumen content, that is to say 5.4.%, the conventional mix properties were obtained and reported as averages of six replicates as presented in Table 4.8.

Table 4.8: Conventional mix properties at optimum bitumen content

	Bulk specific gravity	GMM	Voids	VMA	VFB	Stability	Flow	ITS Dry	ITS wet	Stiffness Index
Test runs	2.410	2.506	3.8	15.0	74.4	16.4	3.34	1150.6	1017.4	4.9
	2.405		4.0	15.2	73.4	15.6	3.29	1100.0	981.6	4.7
	2.403		4.1	15.2	73.0	16.3	3.38			4.8
	2.406		4.0	15.1	73.6	15.4	3.45			4.5
	2.413		3.7	14.9	75.2	15.2	3.38			4.5
	2.410		3.8	15.0	74.5	14.8	3.24			4.6
Average	2.408	2.506	3.9	15.1	74.0	15.62	3.35	1125	1000	4.7

4.4 Partial Replacement of Cement with Cow Dung Ash (CDA) as filler

The effect of partially replacing the 4 % cement filler with the cow dung ash organic filler on the Marshal and volumetric properties of HMA were obtained through Marshal mix procedures for CDA partial replacement as presented in the Table 4.9. These tests were conducted using an optimum bitumen content of 5.4 %.

Table 4.9: Marshal and Volumetric properties with partial replacement with CDA

Property	% CDA replacement of cement filler %				
	0 %	**25%**	**50%**	**75 %**	**100 %**
Bulk Specific Gravity (g/cm^3)	2.408 ± 0.005	2.385 ± 0.003	2.366 ± 0.004	2.343± 0.006	2.325± 0.006
Theoretical Max Specific gravity (g/cm^3)	2.506 ± 0.001	2.485 ± 0.001	2.476 ± 0.001	2.471 ± 0.001	2.464 ± 0.001
Voids in the mix (%)	3.9 ± 0.14	4.0 ± 0.11	4.4 ± 0.15	5.2 ± 0.25	5.6 ± 0.24
VMA (%)	15.1 ± 0.13	15.6 ± 0.10	16.2 ± 0.43	16.9 ± 0.73	17.0 ± 0.21
VFB (%)	74 ± 0.72	74 ± 0.57	72 ± 0.70	69 ± 1.11	67 ± 1.00
Stability (kN)	16.1 ± 0.45	15.7 ± 0.54	16.7 ± 0.25	17.0 ± 0.52	17.5 ± 0.16
Flow (mm)	3.30 ± 0.05	3.33 ± 0.19	3.60 ± 0.25	3.61 ± 0.07	3.58 ± 0.10
Stiffness Index (kN/mm)	4.84 ± 0.20	4.71 ± 0.34	4.65 ± 0.39	4.70 ± 0.18	4.90 ± 0.16

4.4.1 Relationship of Bulk Specific Gravity and Maximum Theoretical Specific Gravity

Bulk specific gravity (Gmb) decreases with the increase in the percentage replacement of cement filler with the CDA filler, that is to say at 0 % CDA (100 % cement) the bulk specific gravity was 2.408 g/cm^3 and declined to 2.325 g/cm^3 at 100 % CDA (0 % cement) as shown in Figure 4.6. Maximum theoretical specific gravity (Gmm) similarly decreased with the increase in the percentage replacement of cement filler with the CDA filler, that is to say at 0 % CDA (100 % cement) the maximum theoretical specific gravity was 2.506 g/cm^3 and declined to 2.464 g/cm^3 at 100 % CDA (0 % cement) as shown in Figure 4.6. This observed behaviour was linked to the specific gravities of the constituent filler materials, such as cement with a specific gravity of 3.059 g/cm^3 and Cow dung ash with a specific gravity of 2.258 g/cm^3.

On the other hand, it was noted that the bulk specific gravity (Gmb) was lesser than the maximum theoretical specific gravity (Gmm) for all the percentage replacement of cement filler with the CDA filler. This is because the maximum theoretical specific gravity excludes air voids while the bulk specific gravity contains air voids traces (Bujang, Aman and Taher, 2022).

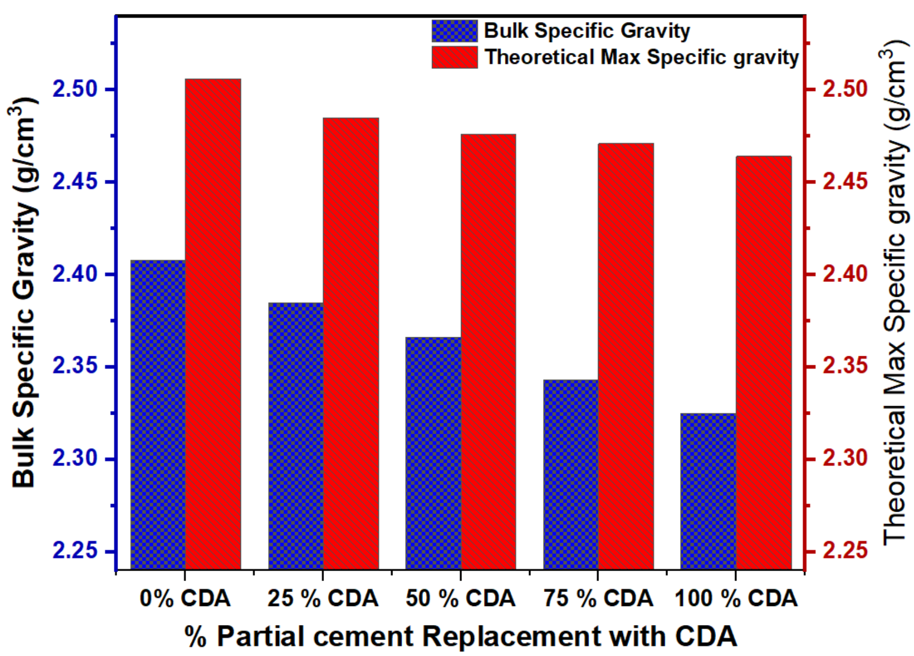

Figure 4.6: Bulk specific gravity and Maximum theoretical specific gravity of % partial cement replacement with CDA

4.4.2 Relationship of Voids in the Mix (V_a), Voids in the Mineral aggregate (VMA) and Voids Filled with Bitumen (VFB) for % Partial Cement Replacement with CDA

From the Figure 4.7 (a), voids increased with the increase in percentage replacement of cement filler with the CDA filler from 3.9 % at 0 % CDA (100 % cement) to 5.6 % at 100 % CDA (0 % cement) replacement. In a compacted mix, voids are highly influenced by the density of the mix, the denser the mix, the fewer the voids and vice versa. Additionally, the size of the filler particles differs in that cement usually with a particle size between 1 - 50 µm has finer particle size than the CDA of particle size, 75 µm. Thus, CDA creates more voids in the mix as its percentage increases with the replacement of the cement filler. It was noted that for percentage replacement of cement filler with the CDA filler of 0 % CDA to 50 % CDA, the voids were within the MoWT general specification 2005 for roads and bridges of 3 – 5 %.

In the Figure 4.7 (b), VMA increased with the increase in percentage replacement of cement filler with the CDA filler from 15.1 % at 0 % CDA (100 % cement) to 17.0 % at 100 % CDA (0 % cement) replacement. This was attributed to increase in the voids content with more CDA filler additions of higher particle sizes compared to the cement filler material. Also, it was noted that VMA of the mix achieved the minimum specification limit of MoWT general specification, 2005 for roads and bridges of 15 %.

Meanwhile in Figure 4.7 (c), VFB decreased with the increase in percentage replacement of cement filler with the CDA filler from 74 % at 0 % CDA (100 % cement) to 67 % at 100 % CDA (0 % cement) replacement. It was observed that up to 50 % replacement of cement filler with the CDA filler lied within the limits of Uganda's MoWT specification, 2005 for roads and bridges of within 70 % - 80 % as indicated in Figure 4.7 (c) for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS). Beyond 50 % replacement, there are more particles to be wetted by the bitumen which leaves a lesser amount of bitumen to fill the voids.

In a study by Abdulrasool *et al.*(2022), 50% replacement of limestone filler by CDA yielded 3.781, 18.647, and 75.765 for Va, VMA and VFB respectively, which are close to the obtained results in this work at 50% replacement of cement with CDA filler in HMA.

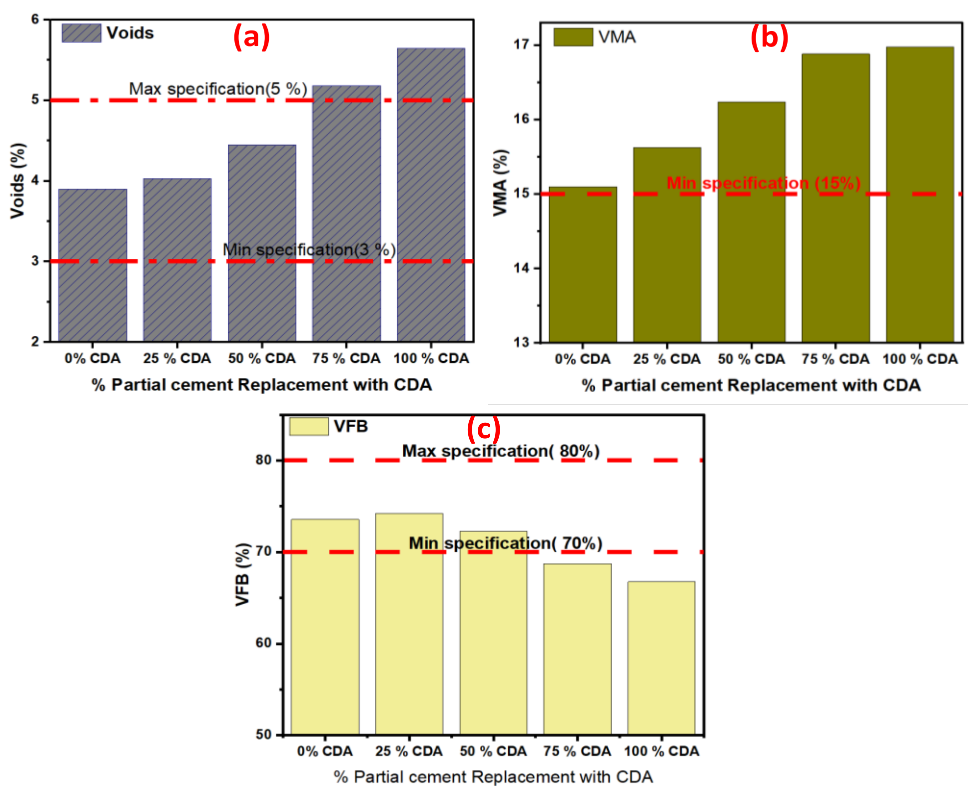

Figure 4.7: (a) Voids in the mix, (b) VMA and, (c) VFB of the % partial cement replacement with CDA

4.2.3 Marshal Stability and Flow

Stability works on a principle of resistance to the plastic flow of a cylindrical specimen loaded laterally. From Figure 4.8 (a), marshal stability increased with the increase in percentage replacement of cement filler with the CDA filler from 16.1 kN at 0 % CDA (100 % cement) to 17.5 kN at 100 % CDA (0 % cement) replacement. The observed improvement in marshal stability was attributed to the higher SiO_2 content (29.67 %) of Cow dung ash than that of cement (20.1 %) which formed dense microstructures within the asphalt mix thus a higher strength (Al-Zarjawi, Mahdi and Abbas, 2020). According to the Uganda's MoWT specification, 2005 for roads and bridges for low-volume traffic roads (less than $1x10^6$ ESAS), the stability achieved were all above the minimum of 6 kN requirement as shown in Figure 4.8 (a). A high stability is a sign that the HMA can take up even higher loading during use.

In Figure 4.8 (b), the flow increased with increase in the percentage replacement of cement filler with the CDA filler from 3.30 mm at 0 % CDA (100 % cement) to 3.61 mm at 75 % CDA (25 % cement) replacement. Flows are the vertical deformation of the briquette recorded as the maximum attained during testing at 60 ^oC. A mix which is more prone to deformation is normally the one with high flow values whereas low flow values may represent a mix with high voids and less binder for long-term performance and result in premature failure since the mix is more brittle. Based on the Uganda's MoWT specification, 2005 for roads and bridges for low-volume traffic roads (less than $1x10^6$

ESAS), the obtained flow for all the tested specimens lied within the acceptable range of 2- 4 mm.

In a study by Abdulrasool *et al*.(2022), 50% replacement of limestone filler by CDA yielded the a Marshall stability of 11.11 kN and a flow of 3 mm which is comparable to the obtained results of 16.7 kN and 3.6 mm respectively, at 50% replacement of cement with CDA filler in HMA.

Based on the Welch two sample t-test, voids, VMA, VFB, stability and flow test values of the conventional cement filler were compared to 50% CDA partial replacement of cement. The variations in voids ($p = 0.0057$) ($p< 0.01$), VMA ($p = 0.0001$) ($p< 0.001$), VFB ($p = 0.027$) ($p< 0.05$) and stability ($p = 0.031$) ($p< 0.05$) were significant. On the other hand, the difference in the voids ($p = 0.05571$) and flow ($p = 0.856$) were not significant ($p > 0.05$).

The Marshal stiffness index which is the ratio of stability to flow generally decreased with increase in the percentage replacement of cement filler with the CDA filler, that is from 4.84 kN/mm at 0 % CDA (100 % cement) to 4.65 kN/mm at 50 % CDA (50 % cement) replacement as indicated in Table 4.9.

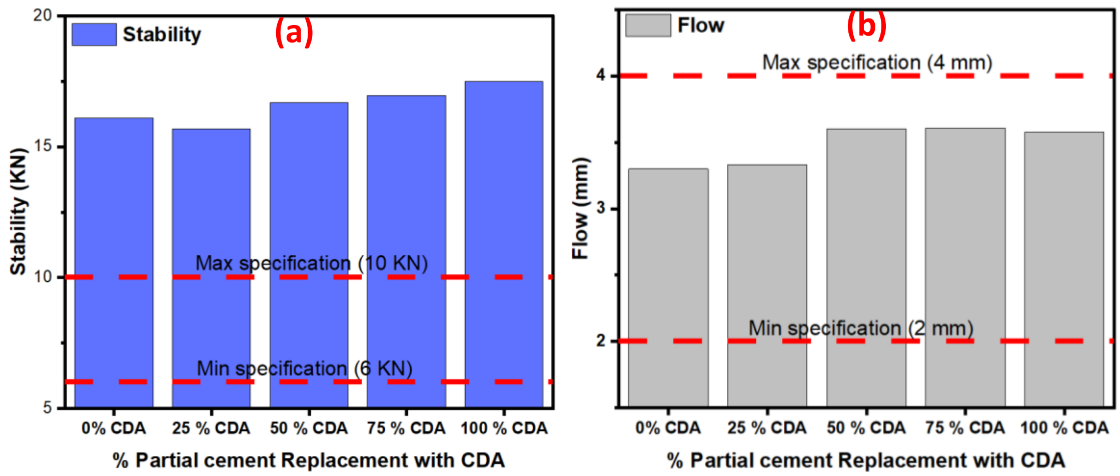

Figure 4.8: (a) Marshal Stability and (b) Flow of the % partial cement replacement with CDA

4.5 Partial Replacement of Cement with Banana Peels Ash (BPA) as Filler

The effect of partially replacing the 4 % cement filler with the Banana peels ash organic filler on the Marshal and volumetric properties of HMA were obtained through Marshal mix procedures for BPA partial replacement as presented in Table 4.10. These tests were conducted using an optimum bitumen content of 5.4 %.

Table 4.10: Marshal and Volumetric properties with partial replacement with BPA

Property	% BPA replacement of cement filler %				
	0 %	**25 %**	**50 %**	**75 %**	**100 %**
Bulk Specific Gravity (g/cm^3)	2.408 ± 0.005	2.377 ± 0.004	2.360 ± 0.002	2.341 ± 0.003	2.319 ± 0.004
Theoretical Max Specific gravity (g/cm^3)	2.506 ± 0.001	2.478 ± 0.001	2.476 ± 0.001	2.459 ± 0.001	2.451 ± 0.001
Voids in the mix (%)	3.9 ± 0.15	4.1 ± 0.12	4.4 ± 0.10	4.8 ± 0.12	5.4 ± 0.15
VMA (%)	15.1 ± 0.12	15.8 ± 0.15	16.1 ± 0.06	16.5 ± 0.12	17.0 ± 0.15
VFB (%)	74.0 ± 0.58	74.3 ± 0.78	72.7 ± 0.36	71.0 ± 0.49	68.4 ± 0.62
Stability (kN)	16.1 ± 0.44	11.24 ± 0.42	10.63 ± 0.92	10.20 ± 0.17	9.97 ± 0.21
Flow (mm)	3.30 ± 0.05	3.22 ± 0.07	3.37 ± 0.14	3.49 ± 0.12	3.56 ± 0.08
Stiffness Index (kN/mm)	4.84 ± 0.20	3.48 ± 0.14	3.15 ± 0.15	2.92 ± 0.15	2.81 ± 0.10

4.5.1 Relationship of Bulk Specific Gravity and Maximum Theoretical Specific Gravity

Bulk specific gravity (Gmb) decreases with the increase in the percentage replacement of cement filler with the BPA filler, that is to say at 0 % BPA (100 % cement) the bulk specific gravity was 2.408 g/cm^3 and declined to 2.319 g/cm^3 at 100% BPA (0 % cement) as shown in Figure 4.9. Maximum theoretical specific gravity (Gmm) similarly decreased with the increase in the percentage replacement of cement filler with the BPA filler, that is to say at 0 % BPA (100 % cement) the maximum theoretical specific gravity was 2.506 g/cm^3 and declined to 2.451 g/cm^3 at 100% BPA (0 % cement) as shown in Figure 4.9. This observed behaviour was linked to the specific gravities of the constituent filler materials, such as cement with a specific gravity of 3.059 g/cm^3 and banana peels ash with a specific gravity of 2.141 g/cm^3.

On the other hand, it was noted that the bulk specific gravity (Gmb) was lesser than the maximum theoretical specific gravity (Gmm) for all the percentage replacement of cement filler with the BPA filler. This is because the maximum theoretical specific gravity excludes air voids while the bulk specific gravity contains air voids traces (Bujang, Aman and Taher, 2022).

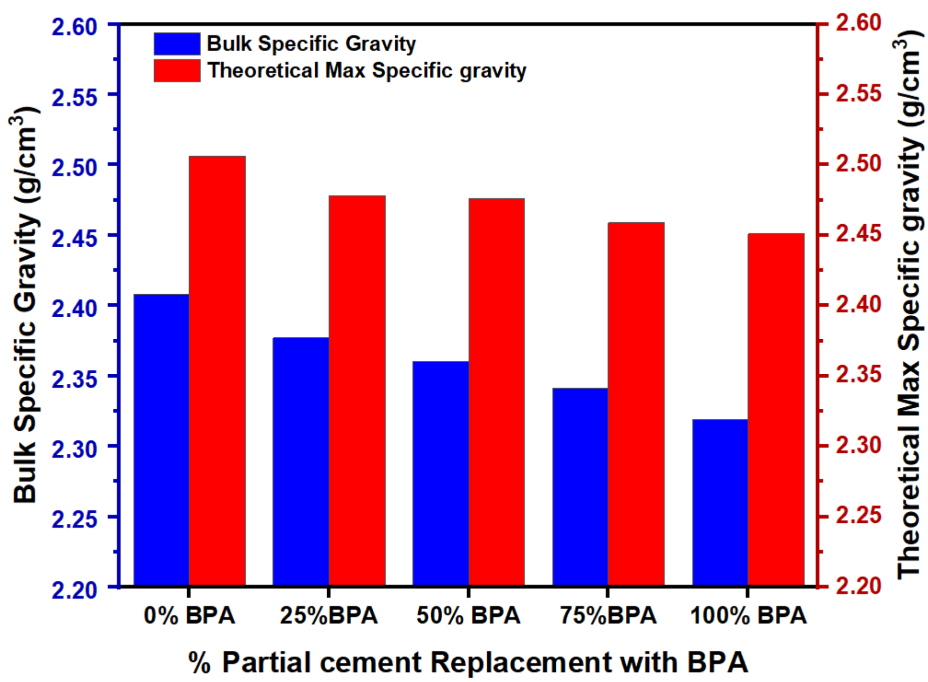

Figure 4.9: Bulk specific gravity and Maximum theoretical specific gravity of % partial cement replacement with BPA

4.5.2 Relationship of Voids in the Mix (V_a), Voids in the Mineral Aggregate (VMA) and Voids Filled with Bitumen (VFB) for % Partial Cement Replacement with BPA

From the Figure 4.10 (a), voids increased with the increase in percentage replacement of cement filler with the BPA filler from 3.9 % at 0 % BPA (100 % cement) to 5.4 % at 100 % BPA (0 % cement) replacement. In a compacted mix, voids are highly influenced by the density of the mix, the denser the mix, the fewer the voids and vice versa. Additionally, the size of the filler particles differs in that cement usually with a particle size between 1 - 50 μm has finer particle size than the BPA of particle size, 75 μm. Thus, BPA created more voids in the mix as its percentage increased with the replacement of the cement filler. It was noted that for percentage replacement of cement filler with the BPA filler of 0 % BPA to 75 % BPA, the voids were within the MoWT general specification 2005 for roads and bridges of 3 – 5 %.

In the Figure 4.10 (b), VMA increased with the increase in percentage replacement of cement filler with the BPA filler from 15.1 % at 0 % BPA (100 % cement) to 17.0 % at 100 % BPA (0 % cement) replacement. This was attributed to increase in the voids content with more BPA filler additions of higher particle sizes compared to the cement filler material. Also, it was noted that VMA of the mix achieved the minimum specification limit of MoWT general specification, 2005 for roads and bridges of 15 %.

Meanwhile in Figure 4.10 (c), VFB decreased with the increase in percentage replacement of cement filler with the BPA filler from 74 % at 0 % BPA (100 % cement) to 68.4 % at 100 % BPA (0 % cement) replacement. It was observed that up to 75 % replacement of cement filler with the BPA filler lied within the limits of Uganda's MoWT specification, 2005 for roads and bridges of within 70 % - 80 % as indicated in Figure 4.10 (c) for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS). Beyond 75 % replacement, there was more BPA particles to be wetted by the bitumen which leaves a lesser amount of bitumen to fill the voids.

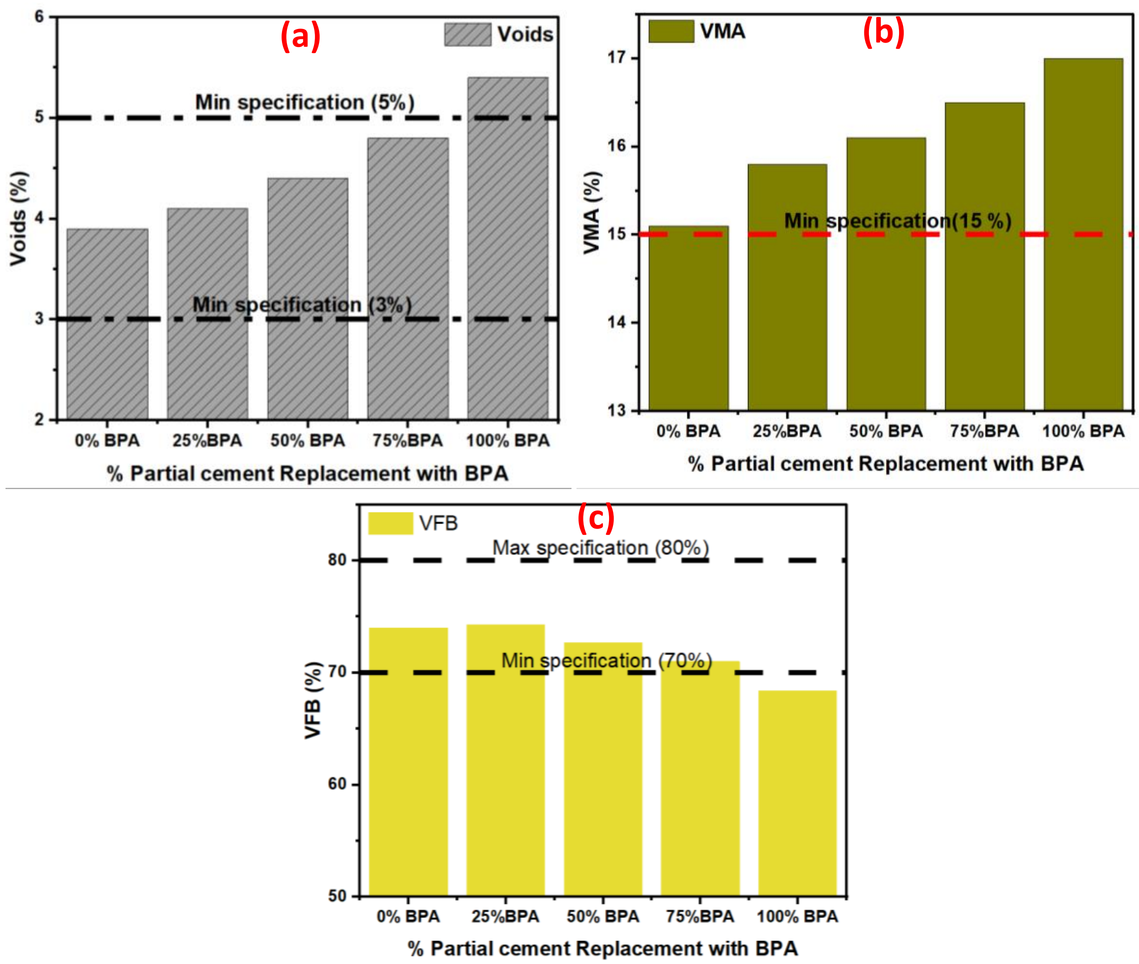

Figure 4.10: (a) Voids in the mix, (b) VMA and, (c) VFB of the % partial cement replacement with BPA

4.5.3 Marshal Stability and Flow

From Figure 4.11 (a), marshal stability decreased with the increase in percentage replacement of cement filler with the BPA filler from 16.1 kN at 0 % BPA (100 % cement) to 9.97 kN at 100 % BPA (0 % cement) replacement. The decline in marshal stability was linked to the lower CaO content (3.47 %) of banana peels ash compared to that of cement (63.7 %). Coexistence of high CaO and SiO_2 enhances the strength (Al-Zarjawi, Mahdi and Abbas, 2020). According to the Uganda's MoWT specification, 2005 for roads and bridges for low-volume traffic roads (less than $1x10^6$ ESAS), the stability achieved up to 75 % replacement of cement filler with the BPA filler was higher than the maximum specification of 10 kN as shown in Figure 4.11 (a).

Also, in Figure 4.11 (b), the flow generally increased with increase in the percentage replacement of cement filler with the BPA filler from 3.30 mm at 0 % BPA (100 % cement) to 3.56 mm at 100 % BPA (0 % cement) replacement. Based on the Uganda's MoWT specification, 2005 for roads and bridges for low-volume traffic roads (less than $1x10^6$ ESAS), the obtained flow for all the tested specimens lied within the acceptable range of 2 - 4 mm.

Comparatively, at 50% replacement of cement with BPA, the obtained Marshall stability of 10.63 kN was lower than that reported at 50% replacement of limestone filler by CDA, 11.11 kN. Meanwhile, closer flow values, 3.37 mm and 3 mm respectively, were noted (Abdulrasool *et al*., 2022).

Meanwhile, the Marshal stiffness index decreased by 42 % with the percentage increase replacement of cement filler with the BPA filler, corresponding to 4.84 kN/mm at 0 % BPA (100 % cement) to 2.81 kN/mm at 100 % BPA (0 % cement) replacement as indicated in Table 4.10.

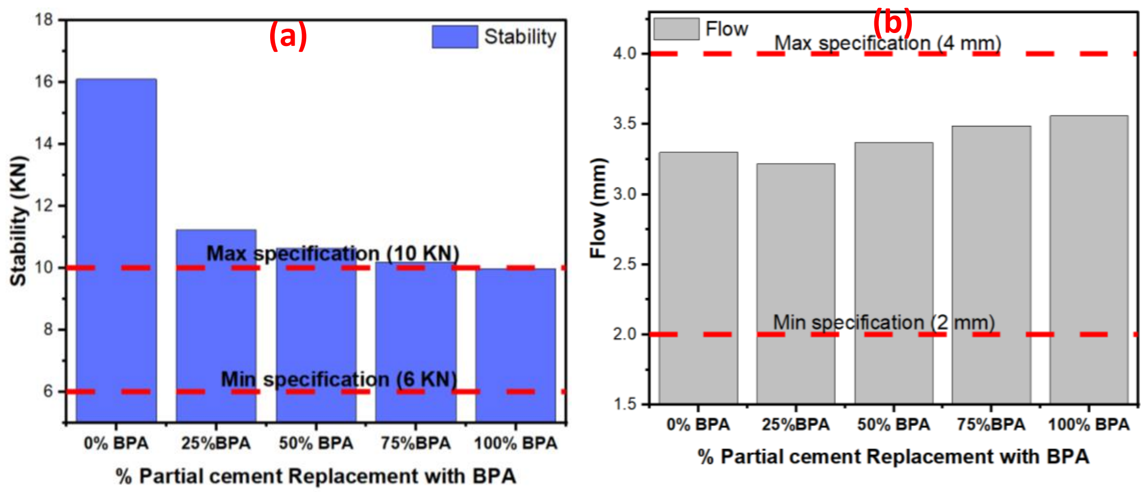

Figure 4.11: (a) Marshal Stability and (b) Flow of the % partial cement replacement with BPA

Based on the Welch two sample t-test, voids, VMA, VFB, stability and flow test values of the conventional cement filler were compared to 50% BPA partial replacement of cement. The difference in voids ($p = 0.0011$) ($p< 0.01$), VMA ($p = 4.192 \times 10^{-07}$) ($p< 0.001$), VFB ($p = 0.013$) ($p< 0.05$) and stability ($p = 0.006$) ($p< 0.01$) were significant. On the other hand, the difference in the voids ($p = 0.05571$) and flow ($p = 0.4441$) were not significant ($p > 0.05$).

4.6 Full Replacement of Cement with Cow Dung Ash (CDA) as Filler in Hot Mix Asphalt

In addition to partially replacing the cement filler with organic fillers of CDA and BPA, further analysis was conducted to evaluate the potentiality of fully replacing the cement filler with the organic fillers in the HMA. Under this, a job mix was carried out while only utilising CDA as a filler in the percentages of 2 %, 4 %, 6 % and 8 %. All the tests were conducted in triplicates.

4.6.1 Determination of Optimum Bitumen Content at Full Replacement with CDA

The optimum bitumen content was determined at the respective filler contents following the procedures as earlier described in Section 4.2.1.1. From Figure 4.12, OBC of 5.4 %, 5.8 %, 7.3 % and 8.3 % were obtained at CDA filler content of 2 %, 4 %, 6 % and 8 % respectively. It was noted that the OBC % increased with the increase in the CDA filler percentage. This was because increase in the CDA filler content increases the surface area and therefore requiring more bitumen to wet it (John, Bangi and Lawrence, 2021).

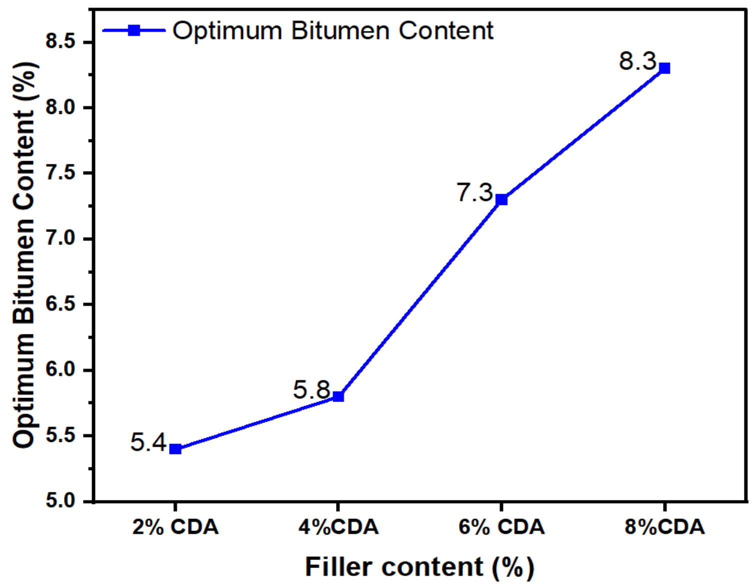

Figure 4.12: Optimum bitumen contents at full replacement with CDA

4.6.2 Marshal and Volumetric Properties of Using CDA as a Filler in Hot Mix Asphalt

Marshal tests were carried out on samples of HMA where CDA was used as filler alone without cement and the results are summarised in Table 4.11.

Property	2% CDA	4%CDA	6% CDA	8%CDA
Optimum Bitumen Content	5.4	5.8	7.3	8.3
Gmb (g/cm^3)	2.374	2.336	2.305	2.287
Gmm (g/cm^3)	2.473	2.431	2.396	2.380
Va (%)	4.02	3.89	3.8	3.87
VMA (%)	15.59	16.92	19.03	20.23
VFB (%)	74.22	77.01	80.05	80.89
Stability (kN)	14.5	13.9	9.6	9.5
Flow (mm)	3.34	3.61	4.55	5.17
ITS (Dry) (Pa)	1032	1009	940	906

ITS (Wet) (Pa)	963	908	801	772
ITSR (%)	93	90	85	85

Table 4.11: Marshal properties of using CDA as filler at different percentages

4.6.3 Relationship of Bulk Specific Gravity and Maximum Theoretical Specific Gravity

Bulk specific gravity decreased by 3.7 % with the increase in the cow dung ash filler content from 2 % to 8 % as shown in Figure 4.13. This was due to the increase in the cow dung ash filler content with a reduction in the other mix constituents such as aggregates. Cow dung ash has a lower density compared to aggregates.

Maximum theoretical specific gravity (Gmm) similarly reduced by 3.7 % with increase in the cow dung ash filler content from 2 % to 8 % as shown in Figure 4.13. This observed behaviour was similarly linked to the specific gravities of the constituent filler materials.

In addition, the bulk specific gravity (Gmb) was lesser than the maximum theoretical specific gravity (Gmm) for all the cow dung filler contents. This is because the maximum theoretical specific gravity excludes air voids while the bulk specific gravity contains air voids traces (Bujang, Aman and Taher, 2022). The difference between the bulk specific gravity (Gmb) and the maximum theoretical specific gravity (Gmm) ranged from 0.091 - 0.099.

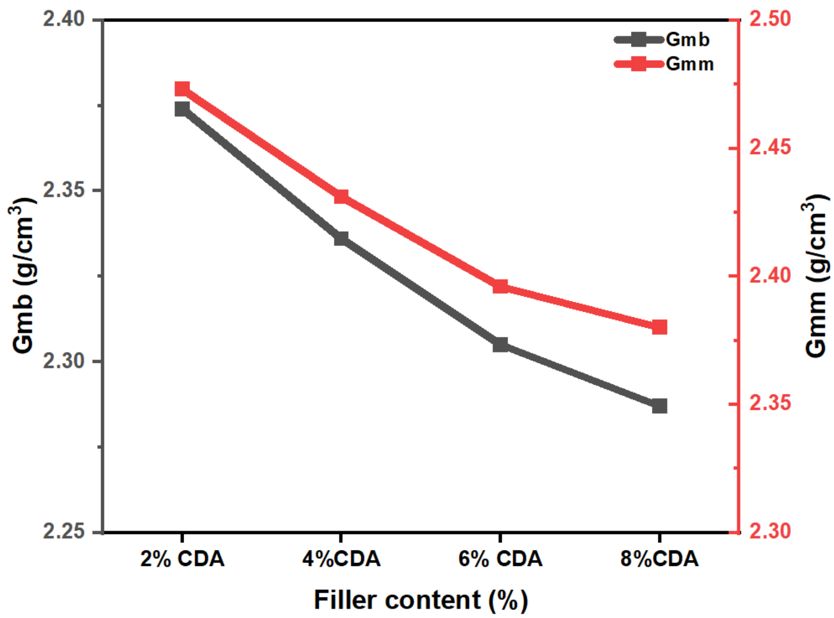

Figure 4.13: Bulk specific gravity and Maximum theoretical specific gravity at various CDA filler contents

4.6.4 Relationship of Voids in the Mix (Va), Voids in the Mineral Aggregate (VMA) and Voids Filled with Bitumen (VFB) for using CDA Filler Material

Voids in the mix when using CDA as the filler material at the different filler percentages did not vary greatly, that is 4.02 % at 2 % CDA filler content and 3.87 % at 8 % CDA filler content as shown in Figure 4.14. This was due to the fact that the specimens were prepared at the optimum bitumen contents.

On the other hand, VMA and VFB increased with the increase in the CDA filler content. VMA increased from 15.59 % to 20.23 % at 2 % and 8 % CDA filler contents respectively. VFB increased from 74.22 % to 80.89 % at 2 % and 8 % CDA filler contents respectively. This phenomenon was attributed to the porousness of the cow dung filler materials which increased the VMA (Fayissa, Kebede and Fufa, 2022). It was noted that VMA of the mix at the different % CDA filler contents achieved the minimum specification limit of MoWT general specification, 2005 for roads and bridges of 15 %. Meanwhile, for the VFB only 2 % and 4 % CDA filler contents met the MoWT general specification, 2005 for roads and bridges of 70 - 80 %.

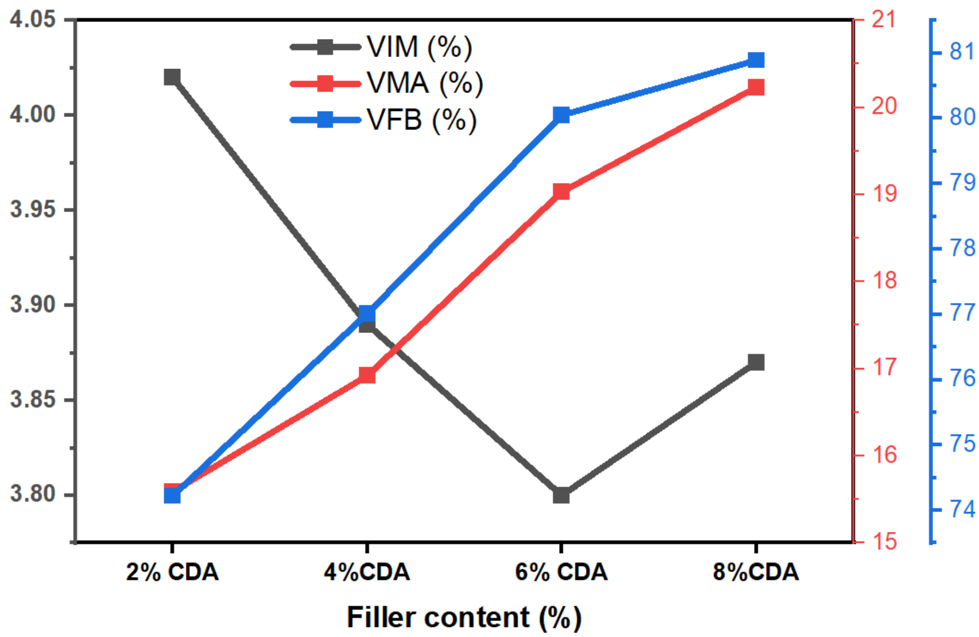

Figure 4-14: Voids in the Mix (Va), Voids in the mineral aggregate (VMA) and Voids filled with bitumen (VFB) for the CDA filler material

4.6.5 Marshal Stability and Flow

From Figure 4.15, Marshal stability decreased with the increase in the CDA filler content from 14.5 kN at 2 % CDA to 9.5 kN at 8 % CDA. This decrease is as a result of increase in VFB as seen from Figure 4.14. As VFB increases, the mix becomes saturated with bitumen and hence weakens the mix. Additionally, increase in the CDA filler content reduces the ability of the aggregates to interlock with each other leading to low stability. According to the Uganda's Ministry of Works and Transport (MoWT) General Specifications, 2005 for Roads and Bridges, all the different prepared CDA filler contents met the maximum requirement of 10 kN.

In Figure 4.15, the flow increased with increase in the CDA filler content from 3.34 mm at 2 % CDA to 5.17 mm at 8 % CDA. this was attributed to the weakened interlocking forces of aggregates as percentages of the CDA filler content increased which led to an increase in the flow. Based on the MoWT general specification, 2005 for roads and bridges, CDA filler content of 2 % and 4 % lied within the specifications range of 2 - 4 mm.

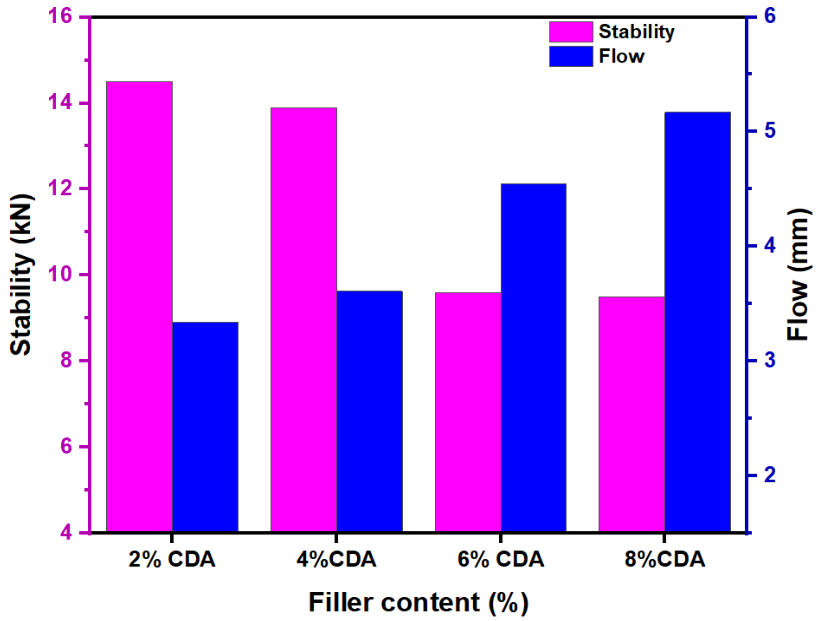

Figure 4.15: Marshal Stability and flow for the CDA filler material

Based on the Welch two sample t-test, the Gmb, voids, VMA, VFB, stability and flow test values of conventional cement filler were compared to 4% CDA full replacement. The variations in Gmb ($p = 5.955 \times 10^{-11}$), VMA ($p = 2.362 \times 10^{-9}$), VFB ($p = 9.81 \times 10^{-5}$), stability ($p = 5.1 \times 10^{-5}$) and flow ($p = 2.32 \times 10^{-6}$) were significant ($p < 0.001$). Meanwhile, that of the difference in the voids ($p = 0.8942$) was not significant ($p > 0.05$).

4.6.6 Indirect Tensile Strength (ITS) and Indirect Tensile Strength Ratio (ITSR)

The indirect tensile strength (dry and wet) reduced with the increase in the CDA filler content. The indirect tensile strength (dry) declined by 12.2 % from 1032 Pa at 2 % CDA filler content to 906 Pa at 8% CDA filler content as shown in Figure 4.16 (a). Meanwhile, the indirect tensile strength (wet) reduced by 19.8 % from 963 Pa at 2 % CDA filler content to 772 Pa at 8 % CDA filler content as also shown in Figure 4.16 (a).

Additionally, the indirect tensile strength ratio (ITSR) reduced with the increase in the CDA filler content, that is from 93 % at 2 % CDA filler content to 85 % at 8 % CDA filler content as shown in Figure 4.16 (b). the ITSR met the minimum requirement of 75 % of the Uganda's MoWT general specification, 2005 for roads and bridges. At higher percentages of CDA filler, the mix is more susceptible to moisture damages since the conditioned strength reduces. This can be attributed to lower content of lime in CDA that makes it hard for the mix to hydrate and increase strength under moisture.

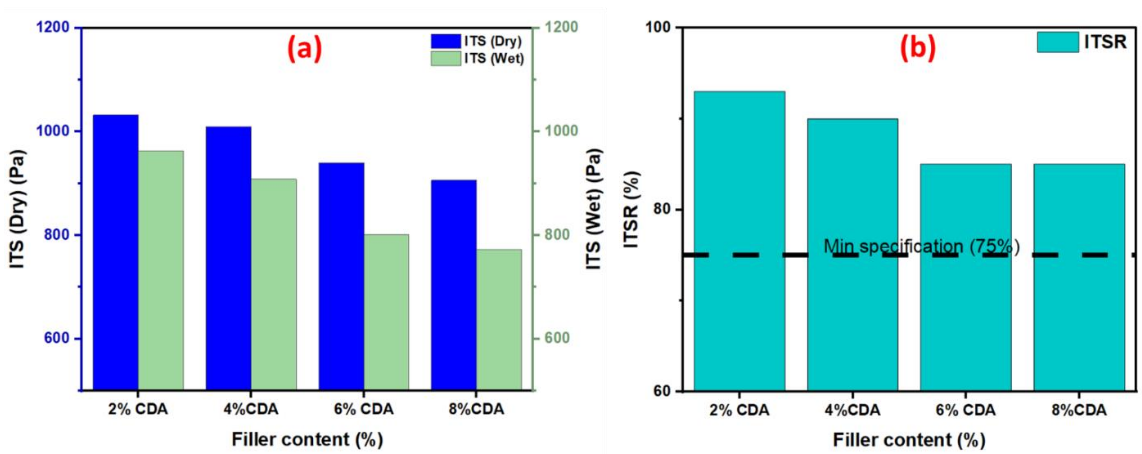

Figure 4.16: Indirect Tensile Strength (ITS) and indirect tensile strength Ratio of CDA filler contents

4.7 Full Replacement of Cement with Banana Peels Ash (BPA) as Filler in Hot Mix Asphalt

Further analysis was conducted to evaluate the potentiality of fully replacing the cement filler with the Banana peels ash as an organic filler in the HMA. Also, in here, a job mix was carried out while only utilising BPA as a filler in the percentages of 2 %, 4 %, 6 % and 8 %. All the tests were conducted in triplicates.

4.7.1 Determination of Optimum Bitumen Content at Full Replacement with BPA

The optimum bitumen content was determined at the respective filler contents following the procedures as earlier described in Section 4.2.1.1. From Figure 4.17, OBC of 5.9 %, 6.3 %, 6.9 % and 7.9 % were obtained at BPA filler content of 2 %, 4 %, 6 % and 8 % respectively. It was noted that the OBC % increased with the increase in the BPA filler content. This was due to increase in the BPA filler content which increased the surface area thus requiring more bitumen to wet it (Ali, 2022).

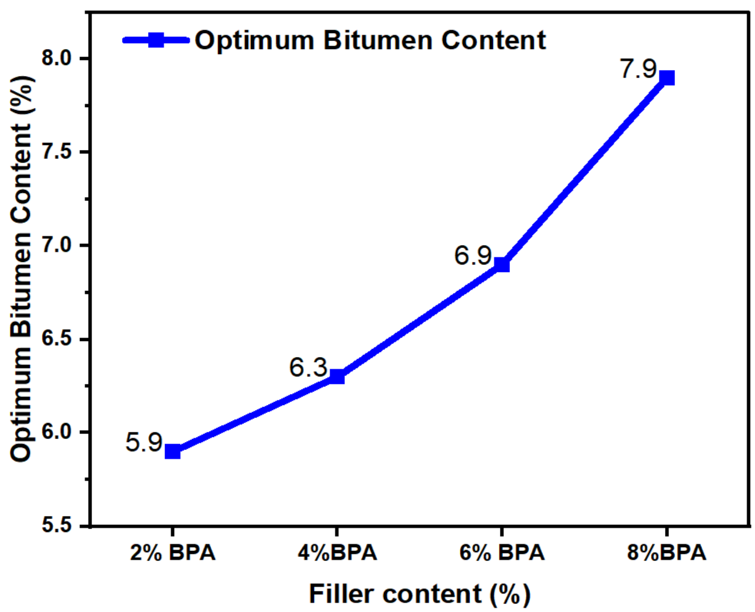

Figure 4.17: Optimum bitumen contents at full replacement with BPA

4.7.2 Marshal and Volumetric Properties of Using BPA as a Filler in Hot Mix Asphalt

Marshal tests were carried out on samples of HMA where BPA was used as filler alone without cement and the results are summarised in Table 4.12.

Table 4.12: Marshal properties of using BPA as filler at different percentages

Property	2% BPA	4%BPA	6% BPA	8%BPA
OBC	5.9	6.3	6.9	7.9
Gmb (g/cc)	2.344	2.341	2.306	2.286
Gmm (g/cc)	2.447	2.441	2.397	2.375
Va (%)	4.23	4.06	3.81	3.74
VMA (%)	16.93	16.98	18.35	19.47
VFB (%)	75.03	76.08	79.22	80.8
Stability (kN)	11.5	10.7	10.7	9.9
Flow (mm)	3.23	3.31	4.19	4.35
ITS(Dry) (Pa)	703	702	487	448
ITS(Wet) (Pa)	668	689	466	427
ITSR	95	98	96	95

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4.7.3 Relationship of Bulk Specific Gravity and Maximum Theoretical Specific Gravity

Bulk specific gravity (Gmb) decreased by 3.7 % with the increase in the Banana peels ash filler content from 2 % to 8 % as shown in Figure 4.18. This was due to the increase in the banana peels ash filler content with a reduction in the other mix constituents such as aggregates. Banana peels ash has a lower density of 2.141 g/cm^3 compared to aggregates.

Maximum theoretical specific gravity (Gmm) similarly reduced by 3.8 % with increase in the Banana peels ash filler content from 2 % to 8 % as shown in Figure 4.18. This observed behaviour was similarly linked to the specific gravities of the constituent filler materials.

In addition, the bulk specific gravity (Gmb) was lesser than the maximum theoretical specific gravity (Gmm) for all the banana peels ash filler contents. This is because the maximum theoretical specific gravity excludes air voids while the bulk specific gravity contains air voids traces (Bujang, Aman and Taher, 2022). The difference between the bulk specific gravity (Gmb) and the maximum theoretical specific gravity (Gmm) ranged from 0.091 - 0.099.

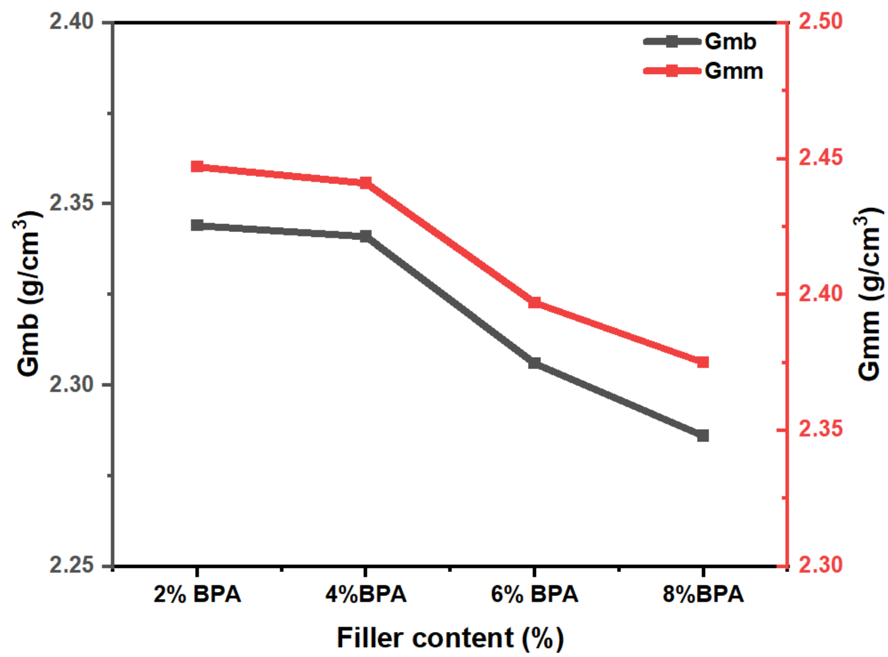

Figure 4.18: Bulk specific gravity and Maximum theoretical specific gravity at various BPA filler contents

4.7.4 Relationship of Voids in the Mix (Va), Voids in the Mineral Aggregate (VMA) and Voids Filled with Bitumen (VFB) for using BPA Filler Material

Voids in the mix when using BPA as the filler material decreased with increase in the BPA filler content, from 4.23 % at 2 % BPA filler content to 3.74 % at 8 % BPA filler content as shown in Figure 4.19. Voids in the mix reduced because more BPA filler was available to fill in the voids in between the aggregates.

Meanwhile, the VMA and VFB increased with the increase in the BPA filler content. VMA increased from 16.93 % to 19.47 % at 2 % and 8 % BPA filler contents respectively. The VFB increased from 75.03 % to 80.8 % at 2 % and 8 % BPA filler contents respectively as shown in Figure 4.19. This was attributed to the porous microstructure of the banana peels ash filler materials which increased the VMA (Akinwumi et al., 2023). It was noted that VMA of the mix at the different % BPA filler contents achieved the minimum specification limit of MoWT general specification, 2005 for roads and bridges of 15 %. Meanwhile, for the VFB only 2 % - 6 % CDA filler contents met the Uganda's Ministry of Works and Transport (MoWT) General Specifications, 2005 for Roads and Bridges of 70 - 80 %.

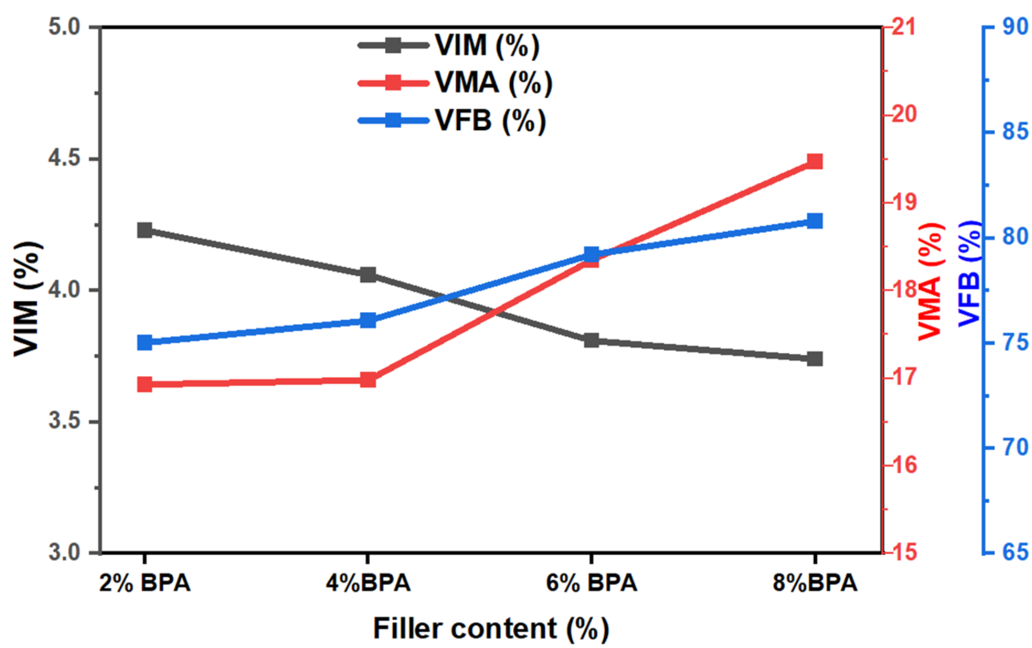

Figure 4.19: Relationship of Voids with BPA filler percentages

4.7.5 Marshal Stability and Flow

From Figure 4.20, Marshal stability decreased with the increase in the BPA filler content from 11.5 kN at 2 % BPA to 9.9 kN at 8 % BPA. This decrease is as a result of increase in VFB as seen from Figure 4.19. As VFB increases, the mix becomes saturated with bitumen and hence weakens the mix. Additionally, increase in the BPA filler content reduces the ability of the aggregates to interlock with each other leading to low stability. According to the Uganda Ministry of Works and Transport (MoWT) General Specifications, 2005 for Roads and Bridges, all the different prepared BPA filler contents met the minimum requirement of 6 kN.

Additionally in the Figure 4.20, the flow increased with increase in the BPA filler content from 3.23 mm at 2 % BPA to 4.35 mm at 8 % BPA. This was attributed to the weakened interlocking forces of aggregates as percentages of the BPA filler content increased which led to an increase in the flow. Based on the Uganda Ministry of Works and Transport (MoWT) General Specifications, 2005 for Roads and Bridges, BPA filler content of 2 % and 4 % lied within the specifications range of 2 - 4 mm.

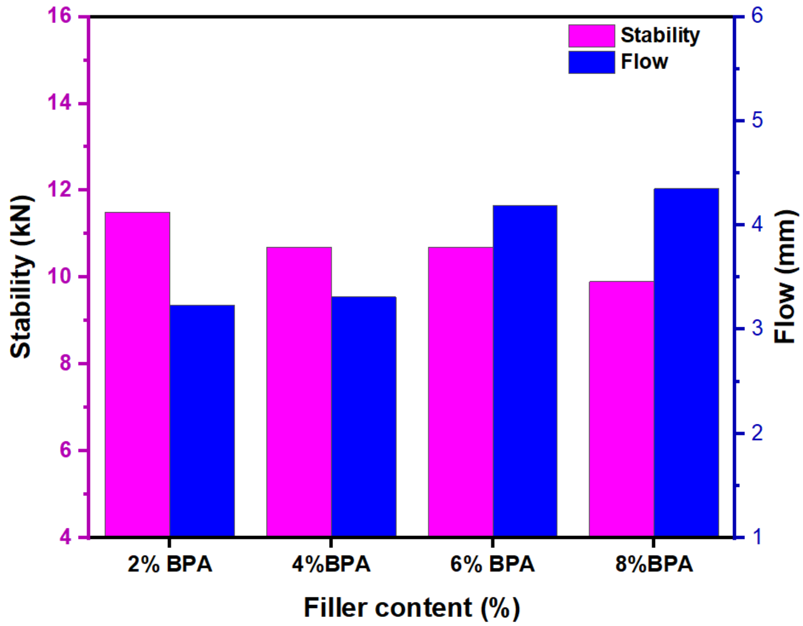

Figure 4.20: Marshal Stability and flow for the BPA filler material

Based on the Welch two sample t-test, the Gmb, voids, VMA, VFB, stability and flow test values of conventional cement filler were compared to 4% BPA full replacement. The variations in Gmb ($p = 4.494 \times 10^{-08}$), VMA ($p = 3.15 \times 10^{-8}$), and stability ($p = 0.00020$) were more significant ($p < 0.001$) compared to that of VFB ($p = 0.001416$), though also significant ($p < 0.01$). On the other hand, the difference in the voids ($p = 0.05571$) and flow ($p = 0.856$) were not significant ($p > 0.05$).

4.7.6 Indirect Tensile Strength (ITS) and Indirect Tensile Strength Ratio (ITSR)

The indirect tensile strength (dry and wet) reduced with the increase in the BPA filler content. The indirect tensile strength (dry) declined by 36.3 % from 703 Pa at 2 % BPA filler content to 448 Pa at 8% BPA filler content as shown in Figure 4.21 (a). Meanwhile, the indirect tensile strength (wet) reduced by 36.1 % from 668 Pa at 2 % BPA filler content to 427 Pa at 8 % BPA filler content as also shown in Figure 4.21 (a).

Meanwhile, the indirect tensile strength ratio (ITSR) generally did not vary significantly with the increase in the BPA filler content as shown in Figure 4.21 (b). The ITSR met the minimum requirement of 75 % of the Uganda's Ministry of Works and Transport (MoWT) General Specifications, 2005 for Roads and Bridges.

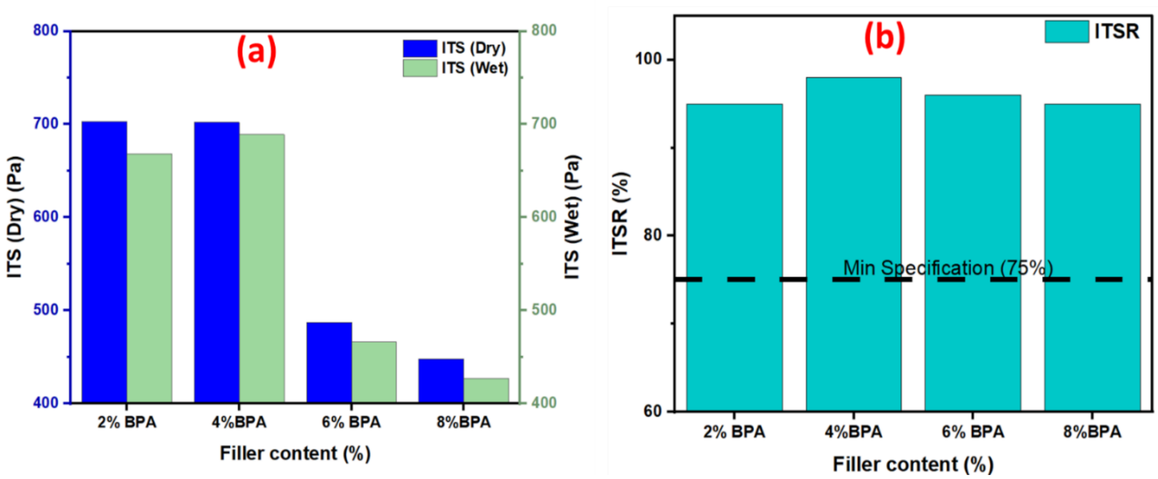

Figure 4.21: Indirect Tensile Strength (ITS) and indirect tensile strength Ratio of BPA filler contents

4.8 Comparison of Optimum Filler Contents under the different mix conditions

Basing on the Uganda's Ministry of Works and Transport (MoWT) General Specifications, 2005 for Roads and Bridges for lighter traffic loading less than 1×10^6 Equivalent standard axle (ESAS), the different prepared filler contents of the mix were compared. From the analysis, the optimum filler contents under the different replacement conditions were obtained. For the partial cement filler replacement, the optimum mix conditions were 50% CDA and 50% BPA while for the full cement filler replacement, the optimum mix conditions were 4% CDA and 4% BPA.

4.8.1 Comparison of Partial Filler Replacement with Organic Fillers

From the Figure 4.22, under partial replacement using the same bitumen content (5.4 %) as the conventional mix, both 50% CDA and 50% BPA revealed a slightly higher voids in the mix of 4.4 % as a result of increased surface area with the addition of the organic fillers as discussed earlier. It was noted that the voids in the mix was still within the requirement ranges of 3 – 5 %. In terms of voids in the mineral aggregate (VMA), both 50% CDA and 50% BPA exhibited higher values of 16.2 % and 16.1 % respectively compared to the conventional filler with 15.1 %. The obtained VMA values were above the minimum requirement ranges of 15 %. For the voids filled with bitumen (VFB), both 50% CDA and 50% BPA portrayed slightly lower values of 72 % and 72.7 % respectively compared to 74% of the conventional filler. The obtained VFB values lied within the specifications for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS) range of 70 – 80 %.

From the Figure 4.23 (a), 50% CDA revealed a slightly higher stability of 16.7 kN compared to 16.1 kN of the conventional filler. Though 50% BPA portrayed a lower stability of 10.63 kN, both 50% CDA and 50% BPA met the minimum requirement for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS) of 6 kN.

In terms of flow, 50% CDA revealed a higher flow, 3.6 mm compared to that of the conventional filler, 3.3 mm. However, 50% BPA exhibited a closer flow of 3.37 mm to that of the conventional filler. The obtained flow values were with the specifications for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS) range of 2 – 4 mm as shown in Figure 4-23 (b).

4.8.2 Comparison of Full Filler Replacement with Organic Fillers

From Figure 4.22, for full filler replacement using bitumen contents of 5.8 % and 6.3 % for 4% CDA filler content and 4% BPA filler content respectively, 4% CDA filler content exhibited close voids in the mix of 3.89 % while 4% BPA filler content revealed higher voids in the mix of 4.06 %. The obtained voids in the mix were still within the requirement ranges of 3 – 5 %. For the voids in the mineral aggregate (VMA), both 4% CDA filler content and 4% BPA filler content exhibited higher values of 16.92 % and 16.98 % respectively compared to the conventional filler with 15.1 %. The obtained VMA values were above the minimum requirement ranges of 15 %. For the voids filled with bitumen (VFB), both 4% CDA filler content and 4% BPA filler content portrayed higher values of 77.01 % and 76.08 % respectively compared to 74% of the conventional filler. The obtained VFB values lied within the specifications for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS) range of 70 – 80 %.

From the Figure 4.23 (a), both 4% CDA filler content and 4% BPA filler content portrayed lower stability of 13.9 kN and 10.7 kN respectively compared to 16.1 kN of the conventional filler. Though both 4% CDA filler content and 4% BPA filler content portrayed a lower stability, both organic filler contents met the minimum requirement for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS) of 6 kN.

In terms of flow, 4% CDA filler content revealed a higher flow, 3.61 mm compared to that of the conventional filler, 3.3 mm. Meanwhile, 4% BPA filler content portrayed a closer flow of 3.31 mm. The obtained flow values were with the specifications for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS) range of 2 – 4 mm as shown in Figure 4.23 (b).

For the ITS (dry and wet), both 4% CDA filler content and 4% BPA filler content portrayed lower ITS values compared to the conventional filler as shown in Figure 4-23 (c). Compared to the conventional filler, ITS dry declined by 10 % for the 4% CDA filler content while for the 4% BPA filler content, it reduced by 37.6 %. Similarly, the ITS wet declined by 9.2 % for the 4% CDA filler content while for the 4% BPA filler content, it reduced by 31.1 %. This implied that BPA filler was more susceptible to moisture induced damages.

The obtained ITSR was 89 %, 90 % and 98 % for the conventional filler, 4% CDA filler content and 4% BPA filler content respectively. The obtained ITSR met the minimum requirement of 75 % for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS) as shown in Figure 4.23 (d).

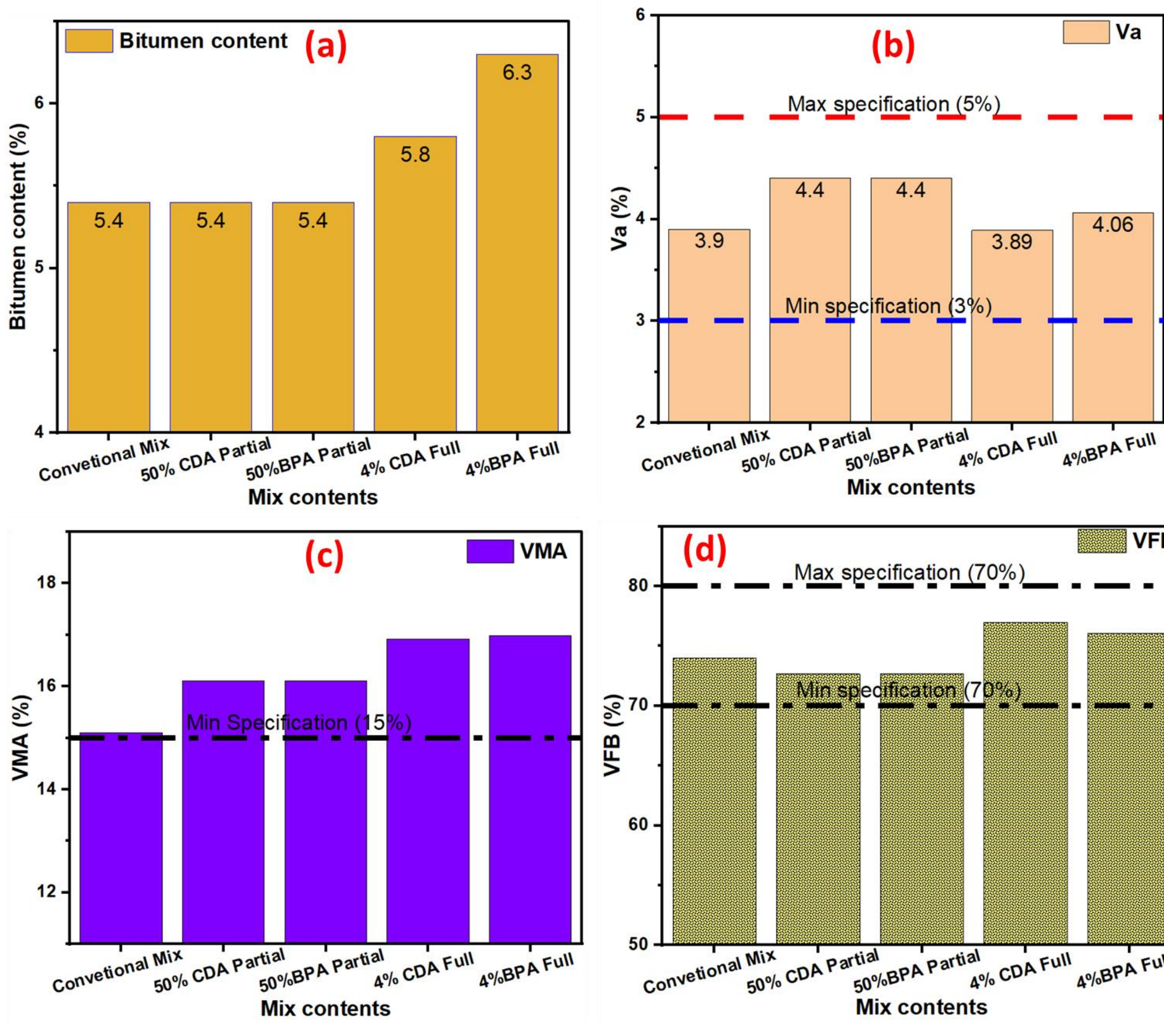

Figure 4.22: (a) Bitumen content, (b) Voids in the mix (Va), (c) Voids in the mineral aggregate (VMA) and (c) voids filled with bitumen (VFB) of optimum contents under the different mix conditions

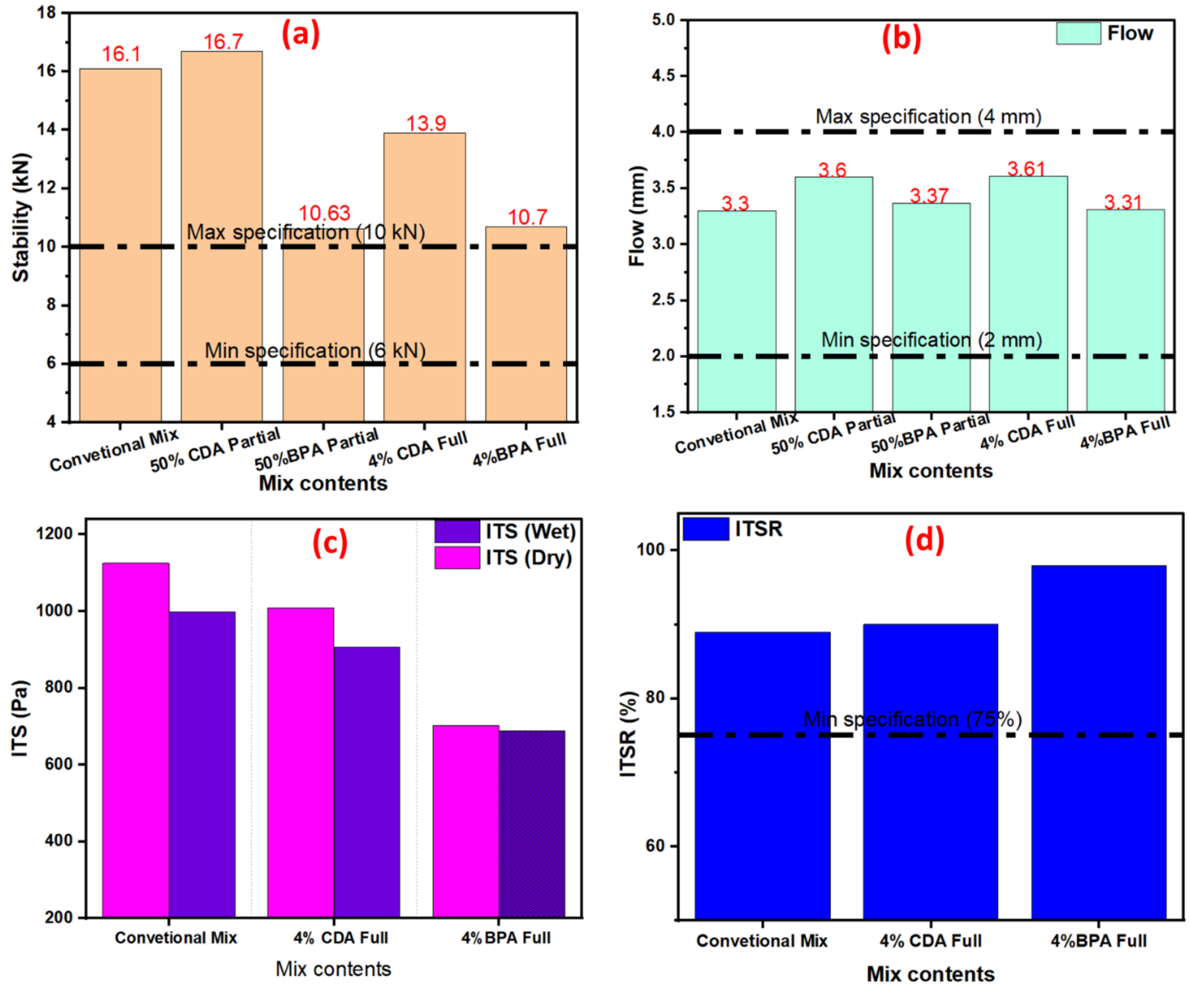

Figure 4.23: (a) Marshal stability, (b) Flow, (c) ITS and (d) ITSR of optimum contents under the different mix conditions

4.9 Summary

In this Chapter, the Marshal and volumetric properties including bulk specific gravity, maximum theoretical specific gravity, voids in the mix, voids in the mineral aggregate, voids filled with bitumen, stability, flow as well as indirect tensile strength in both partial and full cement replacement with organic fillers were obtained. For partial cement replacement, optimum parameters were revealed at 50 % CDA and 50 % BPA. For 50 % CDA, bulk specific gravity, maximum theoretical specific gravity, voids in the mix, voids in the mineral aggregate, voids filled with bitumen, stability and flow were 2.36 g/cm^3, 2.476 g/cm^3, 4.4 %, 16.2 %, 72 %, 16.7 kN, and 3.6 mm respectively. Meanwhile, for 50 % BPA, the respective test values were 2.360 g/cm^3, 2.476 g/cm^3, 4.4 %, 16.1 %,72.7 %, 10.63 kN and 3.37 mm. Conversely, optimum parameters for cement full replacement were obtained at 4 % CDA and 4 % BPA. For 4 % CDA, bulk specific gravity, maximum theoretical specific gravity, voids in the mix, voids in the mineral aggregate, voids filled with bitumen, stability and flow were 2.366 g/cm^3, 2.431 g/cm^3, 3.89 %, 16.9 %, 77 %, 13.9 kN, and 3.61 mm respectively. Meanwhile, for 4% BPA, the respective test values were 2.341 g/cm^3, 2.441 g/cm^3, 4.06 %, 16.98 %,76.08 %, 10.7 kN and 3.31 mm. The indirect tensile strengths were 93 % and 98 % for 4 % CDA and 4 % BPA respectively. From the test results, the developed cow dung ash and banana peels ash materials complied with the Uganda MoWT general specifications for roads and bridges for lighter traffic loading less than 1x10^6 Equivalent standard axle (ESAS).

4.10 Cost comparison/Saving

Cost of incinerating 100 kg of cow dung = 20,000 Ugx

But when cow dung is incinerated only 94.79 % is converted into ash

Therefore, the cost of obtaining 94.79 kg is 20,000 Ugx

Ready CDA filler was obtained by sieving CDA through 0.075 mm sieve and 60 % passed through.

Therefore, the actual CDA = 60 % of 94.79 kg = 56.874 kg

Cost of sieving 1kg of CDA is 100 Ugx

For 94.79 kg x 100 = 9479 Ugx

Cost of 56.874 kg of CDA filler =9,479 + 20,000 = 29479 Ugx

1kg of CDA filler costs 518 Ugx

Average cost of 50 kg of cement = 33,000 Ugx

1kg of cement costs 660 Ugx

Option 1: Conventional (Cement) Filler

Density of asphalt concrete (AC) = 2408 kg/m^3, Bitumen Content = 5.4 %, Length = 1Km, Width = 10 m and thickness of asphalt concrete of 60 mm

Volume of AC in 1 Km = 1000 m x 10 m x 0.06 m = 600 m^3

Mass of AC in 1 Km = 2408 x 600 = 1,444,800 Kg

Weigt of 5.4% Bitumen = 1,444,800 x 0.054 = 78,019.2 Kg

Mass of Aggregates = 1,444,800 – 78,019.2 Kg = 1,366,780.8 Kg

Mass of 4% filler = 1,366,780.8 x 0.04 = 54,671.232 Kg of CDA

Cost of 4% Cement filler = 54,671.232 x 660 =36,083,013 Ugx

Option 2: Partial replacement of 4% filler using 50% cement 50% CDA

Density of asphalt concrete (AC) = 2366 kg/m^3, Bitumen Content = 5.4%, Length = 1Km, Width = 10 m and thickness of asphalt concrete of 60 mm

Volume of AC in 1Km = 1000 m x 10 m x 0.06 m = 600 m^3

Mass of AC in 1 Km = 2366 x 600= 1,419,600 kg

Weigt of 5.4% Bitumen = 1,419,600 x 0.054 = 76,658.4 kg

Mass of Aggregates = 1,419,600 - 76,658.4 kg = 1,342,941.6 kg

Mass of 4% filler = 1,342,941.6 x 0.04 = 53,717.664 kg

Mass of CDA filler = Mass of Cement = 53,717.664/2 = 26,858.832 kg

Cost of CDA = 26,858.852 x 518 = 13,912,874.98 Ugx

Cost of Cement = 26,858.852 x 660 = 17,726,829.12 Ugx

Total Cost of Filler of 50% Cement & 50% CDA in 1km = 13,912,874.98 +17,726,829.12

= 31,639,704.1 Ugx

Saving per km of AC Road Construction = 36,083,013.12 – 31,639,704.1

= 4,443,309.02 Ugx (12.3%)

Option 3: Full replacement of cement with CDA

Density of asphalt concrete (AC) = 2336 kg/m^3, Bitumen Content = 5.8%, Length = 1Km, Width = 10 m and thickness of asphalt concrete of 60 mm

Volume of AC in 1Km = 1000 m x 10 m x 0.06 m = 600 m^3

Mass of AC in 1Km = 2336 x 600= 1,401,600 kg

Weigt of 5.8% Bitumen = 1,401,600 x 0.058 = 81,292.8 kg

Mass of Aggregates = 1,401,600 - 81,292.8 kg = 1,320,307.2 kg

Mass of 4% filler = 1,320,307.2 x 0.04 = 52,812.288 kg of CDA

Cost of 4% CDA filler = 52,812.288 x 518 =27,356,765.18 Ugx

Saving per km of AC Road Construction = 36,083,013.12 – 27,356,765.18

= 8,726,247.94 Ugx (24.2%)

Note that this cost analysis was based on the actual cost incurred during the research on small scale production of CDA therefore, for a large production of CDA, a bigger saving can be realised.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

Physical and mechanical properties of aggregates, bitumen, cow dung ash, banana peels ash and cement were explored and found to be suitable for use in hot mix asphalt.

The incorporation of filler materials derived from banana peels ash and cow dung ash led to a decrease in the Marshall and volumetric characteristics of the hot mix asphalt.

Based on the tested marshal and volumetric properties, cow dung ash filler contents of up to 50 % partial replacement of the 4 % cement filler content revealed favourable properties. Among them 50 % CDA was chosen as the optimum to benefit from increased inclusion of the cow dung ash content. Similarly, banana peels ash filler contents of up to 50 % partial replacement of the 4 % cement filler content exhibited adequate properties.

Full utilisation of 4% cow dung ash filler content revealed appropriate marshal and volumetric properties in terms of voids in the mix, voids filled with bitumen, marshal stability, flow and indirect tensile strength ratio. Moreso, for the banana peels ash, 4% banana peels ash filler content was the optimum.

The marshal and volumetric properties of partial replacement up to 50% of cow dung ash and banana peels ash were within the requirements of MoW&T general specifications for roads and bridges. For partial replacement above 50% of cow dung ash and banana peels ash, the marshal and volumetric properties did not meet the requirements of MoWT general specifications for roads and bridges

At full utilisation of 4 % cow dung ash and 4 % banana peels ash filler contents, the Uganda Ministry of Works and Transport (MoWT) general specifications for roads and bridges for lighter traffic loading less than $1x10^6$ Equivalent standard axle (ESAS) were also met. both cow dung ash and banana peels ash filler contents, proportions above 4 % required more bitumen contents implying an increase in the cost of the road construction materials.

Replacement of cement with cow dung ash or banana peels ash contributes to the use of green materials in roads construction, which is in line with the Sustainable Development Goals, that is SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action).

5.2 Recommendations

From this study, it is recommended that a comprehensive life cycle analysis be conducted to assess the environmental impact of incorporating cow dung ash and banana peels ash as filler materials in hot mix asphalt.

Additionally, exploring the hybridization potential of these two filler materials within the hot mix asphalt composition should be considered.

To further enhance the understanding of the performance of these filler materials, it is desirable to carry out fatigue life, stiffness, and static creep testing.

A comprehensive cost analysis of using cow dung ash and banana peels ash as filler materials in the hot mix asphalt should be undertaken.

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