PERFORMANCE OF BITUMEN AND BITUMINOUS MIX MODIFIED WITH SHREDDED WASTE PLASTIC BAGS AND WASTE SUGAR CANE ASH FOR ROAD WEARING COURSE.

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(Construction Engineering and Management)

JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

2017

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A Thesis Submitted in Partial Fulfillment for The Master of Science in Construction Engineering and Management in Jomo Kenyatta University of Agriculture and Technology

2017

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

This work is dedicated to my children, for their love and support.

ACKNOWLEDGEMENTS

I wish to sincerely thank my God the giver of life for His providence. I would love to express my immense gratitude to my thesis supervisors Mr. S. M Mulei and Professor Z. A. Gariy for their guidance, understanding, kind support, encouragement, patience, and valuable discussions in writing this thesis.

I am greatly indebted to the Ministry of Public Works Material laboratory and Nairobi University for allowing me to carry out laboratory tests in their laboratories. To Wallace Otieno my Research Assistance, for the assistance he accorded me during the testing and collection of the materials. Special thanks to my husband for absolute unquestionable belief in me, which has been a source of encouragement throughout the compilation of this Thesis.

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ABBREVIATIONS

WSCA	Waste Sugar Cane Ash.
SWPB	Shredded Waste Plastic Bags
AAV	Aggregate Abrasion Value
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
CM	Centimeters
FI	Flakiness Index
g	Grams
HMB	Hot Mixed Bitumen
KAM	Kenya Association of Manufacturers
Kg	Kilograms
KIPPRA	Kenya Institute of Public Policy Research and Analysis
GOK	Government of Kenya
KN	Kilo Newton
LAA	Los Angles Abrasion
LDPE	Low Density Polyethylene
M	Meter
ML	Milliliters
mm	Millimeter

μm Micrometer

NEMA National Environment Management Authority

OBC Optimum Binder Content

OPC Ordinary Portland Cement

RMLF Road Maintenance Levy Fund

RTFOT Rolling Thin Film Oven Test

SS Bulk Specific Gravity

SS Specific Gravity

SSS Sodium Sulphate Soundness

Sq.Cm Centimeters Square

TFOT Thin Film Oven Test

UNEP United Nations Environment Programme

UNDP United Nations Development Programme

VFB Voids Filled with Binder

VIM Voids in the mix

VMA Voids in Mineral Aggregates

W Weight

WDC White Dust Cement

PE Polyethylene

PP Polypropylene

EVA	Ethylene-vinyl acetate
EBA	Ethylene-butyl acrylate
SBS	Styrene-Butadiene-Styrene
SIS	Styrene-Isoprene-Styrene
SEBS	Styrene ethylene/Butylene-Styrene

ABSTRACT

Any improvement on the quality of bitumen is a great achievement as it is a major component in road construction material providing its ability to sustain traffic loading. Bituminous paved road fails or get damaged if it is no longer able to sustain traffic or other environmental loading. They fail through poor road maintenance, pot-hole development, overloading among other factors. Convectional bitumen can be modified using waste sugar cane ash (WSCA) and shredded waste plastic bags (SWPB) to improve its mechanical properties as well as solving their disposal problem

The main objective of this study was to understand the fundamental behavior of the modified bitumen, evaluate its mechanical property, and determine optimum mix proportion of the waste to modify conventional bitumen grade 80/100.

The physical properties of the material used in road construction were investigated to ascertain their suitability in road construction. The test carried out to assure the quality of aggregates with modified bitumen includes aggregates impact value, crushing test, Los Angeles Abrasion test, flakiness index, specific gravity and water absorption test. The results were found to be satisfactory. While the tests carried out on the bitumen samples included penetration test, softening point, ductility and bulk specific gravity to ensure its suitability to its grade for being used for wearing course. The procedure for Marshall Stability test was standardized by using America Society for Testing and Material (ASTM D-1559) to determine the optimum binder content of different mixes.

The results obtained from the tests carried out on modified bitumen and modeled briquettes were within the recommended standard specifications. The optimum bitumen content value was 5.5% and a stability value of 14,400N. Penetration index values were in the range of 61 to 68mm and softening point value in the range of 51.3 to 57.8^{o}C. The other test results values were for the aggregates strength 20.6%, water absorption 0.69% while durability test was 2%. The conventional bitumen was modified using 3% SWPB and 2.5% WSCA by reducing the bitumen content in the mix with the same percentage.

From this study, modified bituminous mix has the ability to withstand high temperature, higher load compared to conventional mix and this will minimize the development of rutting and cracking of the wearing course reducing water seepage through the pavement surface. The construction cost of the wearing course can be reduced by approximately 3.0 and 2.5% when SWPB and WSCA is used respectively for modification. It is recommended that the convectional bitumen commonly used in Kenya 80/100 should be modified using WSCA or SWPB to make it a better binder for road construction.

CHAPTER ONE

INTRODUCTION

1.1 Background Study

Road transport plays an important role in the development of the Kenyan economy as it accounts for over 80% of passenger and goods movement in Kenya (Analysis, 2001). Kenya depends on the agriculture for its economy, and thus an efficient road infrastructure is a prerequisite for its socio-economic development. A well-developed road network will facilitate the transportation and marketing of farm produce, while bad roads impede the movement of commodities and services from producers to consumers and farm produce from rural area to urban centers (Frankline, 2007)). Poor road network increases the cost of farm inputs, impede access to the market consequently raising the cost of living. They also constrain access to essential services such as healthcare, education and emergency responses in the event of disasters.

The majority of road network in Kenya constitute unpaved roads as opposed to paved road surfaces. To improve the road network, more and more roads need to be constructed to paved surface standards. There are three main types of paving used in Kenya as follows:

a) Flexible paving made using bituminous mix,

b) Rigid paving made of concrete surfacing,

c) Paving block surface made with pre-cast road paving blocks.

Road networks mostly apply to flexible paving because it is cheaper and easier to construct although it has generally shorter life span compared to rigid and paving block. One of the main components of flexible road surface construction is bitumen. It is important to use bitumen with higher mechanical properties in order to achieve a sound and durable road surface by improving the physical properties of bitumen. This project aims to achieve that broad objective. Discussion in this study will be limited to flexible pavement surface.

The term bituminous materials are generally taken to include all materials consisting of aggregates bound with bitumen. Initially roads were being constructed using the principles developed by Macadam water bound graded aggregates. Under the action of pneumatic tyres and high speed vehicles, lots of dust was generated and the need to come up with tar as surface dressing binder was necessary. The benefit of using tar as a binder was quickly outweighed by the benefits of bitumen and also the fact that tar is carcinogenic in nature making it unacceptable binder in road construction(Chakroborty & Das, 2003). Bitumen was found to be less temperature-susceptible than tar. At high temperatures bitumen is stiffer than its own equivalent grade of bitumen making it more resistant to deformation. While at low temperature bitumen is softer than tar making it less brittle and more resistant to cracking (G.D. Airey, 2004).

Deterioration of bituminous roads has prompted civil engineers to keep investigating on better binder until a strong one is obtained. There are two areas that can improve the serviceability of a road surface. Either by applying a thicker bituminous mixture which increases the construction cost or using a bituminous mixture with modified characteristics (Mamlouk & Zaniewski, 2011).

According to (Gro Harlem Brundtland, Mansour Khalid, Susanna Agnelli, 1987)in their Brundtland Commission, they defined sustainable development as that development that meets the needs of the current generation without compromising the ability of future generations to meet their own needs. In line with this, the researchers have focused their studies on the utilization of industrial and agricultural waste produce by combining them with virgin engineering materials. This helps in strengthening the materials, minimize on environmental pollution, economic gain as well as save on natural extraction of that particular virgin engineering materials.

Based on this study, the need to modify conventional bitumen to enhance its properties as a surface dressing material is important. Any additives added to the bitumen alter its mechanical properties making it better in strength assisting it to bear much more loading (Al-Mansob et al., 2014). Once an additive has been used on conventional bitumen to alter its mechanical properties, the resulting bitumen is referred to as *modified bitumen*. Past researches have indicated that modified bitumen has been used in the construction of bituminous.

This study has addressed modification of bitumen by replacing a certain percentage of bitumen with the same amount of additives. The additives that were used in the modification of bitumen were shredded waste plastic bags and waste sugar cane ash. It will establish the effect of SWPB and WSCA on bitumen, bituminous material, any cost saving and suggest the optimum percentage of bitumen that can be replaced by SWPB and WSCA for the improvement of binder.

Agricultural waste material such as rice husk ash, wheat straw ash, hazel nutshell and sugarcane bagasse ash (referred here as Waste Sugar Cane Ash) has been used in the in preparation of concrete blocks due to their pozzalanic properties (Ganesan K, Rajagopal K, 2007). The stability of bitumen was found to improve when cement, fly ash and stone dust were added to paving bitumen (Mohi, Din, & Marik, 2015). Based on this, WSCA having similar characteristics with rice husk ash and wheat straw ash can be used as a bitumen modifier.

Shredded waste plastic bags have been used in the past as bitumen modifier. They are readily available as packaging materials by supermarkets and other industries and take thousands of years to disintegrate (Eunice Muchane and Grace Muchane (2006), n.d.). The waste plastic bags are so light such that a little breeze easily lifts them up and litter them along highways, waterways and in tress. Waste plastic bags end up choking the solid waste dump sites, drainage channels, rivers, agricultural lands and even streets and playgrounds (Ong'unya Raphael Odhiambo, Aurah Cathrine Musalagani & Ruth, 2014)

In kenya, construction of bituminous road is carried out commonly using bitumen grade 80/100. This bitumen grade is softer and is more susceptible to temperatures changes as compared to bitumen grade 60/70. Their penetration parameters can be lowered by the additional of additive limiting them to be grade 60/70. Use of these waste products would have the double benefit of solving the environmental problem and improve the bitumen quality.

1.2 Problem Statement

The state of road network in Kenya is poor with most road unpaved and many paved roads going for long periods without maintenance. The need for maintenance increases as a road ages. The road surface becomes fragile and less resilient in carrying the loading. This leads to defects which consequently allow water to percolate to the underlying layers causing effectual road failure. Road failures lead to traffic jams for long hours, loss of man hours for drivers and passengers as well as increased air pollution from gas emissions.

Use of modified bitumen would result in road pavements with longer design life. Using locally available admixtures to modify bitumen would give an additional benefit to the local economy in the long run. When such a material is a waste or a by-product, the benefits are even higher as this helps to maintain the environment and provide a beneficial use of the waste. WSCA is readily available as by-product by the numerous sugar factories in Kenya. SWPB is one of the largest constitute of solid waste in Kenya. Both types of waste have tremendous environmental degradation effect by chocking of solid waste dump sites and landfills, chocking of rivers and streams, and destruction of agricultural land.

1.2.1 Overall Objective

The main objective of this study is to evaluate the performance of bitumen and bituminous mixture, modified with waste sugar cane ash and shredded waste plastic bags for road wearing course.

1.2.2 Specific Objectives

The specific objectives of this research study are listed below: -

i. To evaluate the performance of conventional bitumen modified with shredded waste plastic bags and waste sugar cane ash and determine the optimum mix proportions of the plastics and ash in the modification for road wearing course.

ii. To evaluate the stability, flow value and volumetric properties of bituminous mix with and without additional of shredded waste plastic bags, Waste sugar cane ash and the blend of the two waste.

iii. To analyze the cost impact on the use of modified bitumen over the convention one.

1.3 Justification of the study

Bitumen is among the oldest engineering materials (Mulder, 1995)and has been used for thousands of years in various ways; as adhesive, sealant, preservatives, waterproofing agent and pavement binder (Polacco, 2005). Initially bitumen was used in its natural occurrence as there were no refineries, but in the early 1900s, developed countries like USA began to refine bitumen (Morgan and Mulder, 1995). Since then, the world consumption of bitumen has increased rapidly, most of which is used in road construction. A joint publication done by Asphalt Institute and Eurobitumen in 2011, stated that the world consumption of bitumen by that time was approximately 102 million tonnes per year and 85% of which was used in pavement construction (Zhu, Birgisson, & Kringos, 2014)

Road industry has developed rapidly all over the world in the last few decades, especially in developing countries as witnessed in Kenya. Following this rapid development and higher traffic volume, there is great need for bitumen for new road construction and maintenance of the existing ones.

In the vision 2030 document under infrastructure, the Government of Kenya (GOK) aims at providing a cost-effective world-class infrastructure facilities and services in support of the economy (GoK, 2007). Due to this, the demand for bitumen in Kenya has gone higher to cater for its growing infrastructure that has been expanding by the year. In order to obtain bitumen with enhanced quality, there is need to use modified bitumen. This will extend the service life of the road surface by improving the performance of bituminous mixture. This is also important as it will provide a disposal route for waste plastic bags and waste sugar cane ash.

Successful modification of bitumen as envisaged in this study would have a beneficial impact on the economy and the environment. The economy would improve by saving on road construction and maintenance cost, establishment of bitumen modification companies, beneficial usage of waste products, and job creation. The environment would benefit by providing an environmentally friendly disposal route for waste plastic bags and waste sugar cane ash. Modification of bitumen will also reduce in the extraction of bitumen taking care of the future generation (Gro Harlem Brundtland, Mansour Khalid, Susanna Agnelli, 1987).

1.4 Scope and limitations of study

The study focused on the modification of bitumen using Waste Sugar Cane Ash and Shredded Waste Plastic Bags. The penetration test, ductility test, softening point test, and specific gravity tests were carried out to determine the quality of the modified bitumen. Marshall Stability test was used in determining the volumetric properties, stability and flow of the briquette. The following were the limitation of the study

i. This study was limited to the bitumen used on the wearing course alone. The investigator has assumed that the other pavement layers like sub-grade, sub-base and base courses have been done to road designer’s satisfaction and they can adequately support the wearing course.

ii. The aggregates properties were limited to aggregates purchased from Mlolongo Quarry.

iii. The waste sugar cane ash used in this study was from Mumias Sugar Company.

iv. The shredded waste plastic bag was obtained from Kariobagi light industries.

v. The SWPB and WSCA were limited to particle sizes passing through sieve 2.36mm.

CHAPTER TWO

LITERATURE REWIEW

2.1 Introduction

2.1.1 Behavioral Characteristics of bitumen.

Bitumen can be defined as a civil engineering construction material manufactured by extracting the lighter fractions such as liquid petroleum gas, petrol and diesel from heavy crude oil during refining process and is commonly referred to as refined bitumen (Bejjenki, 2015). One of the characteristics and advantages of bitumen as an engineering construction and maintenance material is its great versatility. Bitumen can be liquefied by applying heat, dissolved in solvents, emulsified and modified. Bitumen is used as a binder in road construction by mixing it with graded aggregates to form bituminous mixture which is later laid on the road surface as a wearing course. The main function of the wearing course is to spread traffic and environmental loading applied on the road surface to the other unbound road layers, protect the other road layers from adverse environmental effects and give road users a smooth ride.

For bitumen to be usable in road construction, it must be fluid enough to coat all aggregates and stiff enough when load is applied to it to resist deformation (Bejjenki, 2015). Bitumen has various properties that determine its performance and this includes adhesion, elasticity, plasticity, viscoelasticity, and temperature susceptibility.

Adhesion is the process in which dissimilar particles or surfaces are held together by varying forces and or interlocking forces (Raquel Moraes, Raul Velasquez, 2010). This quality of bitumen is expected to hold the aggregates together at all weather condition enabling the aggregates to carry the traffic and environmental loading applied to it. However, in the presence of water, the adhesion may be affected. It is therefore necessary to dry the aggregate well before coating them with bitumen and use non-porous aggregates when constructing the road.

Elastic behaviour of bitumen can be seen when the binder is able to recovers most or all of its initial shape when the load that caused the deformation is removed (Raquel

Moraes, Raul Velasquez, 2010). This implies that the binder is able to deform when a load is applied to it and recover to its original shape when that particular load has been removed. This property of the binder is commonly used to determine the fatigue resistance or its ability of the binder to absorb large stresses with minimum cracking or deforming (Rossmann Sanral, Sabita .T.M. Gilbert, J.A. Grobler, 2002). It is an important property of the binder as it enables the road surface to deform upon loading and gain its original shape once the load. If bituminous surfaces are able to retain their elasticity, the durability of the same is enhanced.

Also, bitumen is a viscoelastic material in nature. Its rheological properties are very sensitive to temperature and rate of loading (Ali, Mashaan, & Karim, 2013). At higher temperatures there is more flow, while at lower temperatures the bitumen tends to be stiff and elastic, while at intermediate temperatures, it tends to be visco-elastic (C.A. Emeritus, 2002). Temperature susceptibility of the binder being used in a paving mixture is crucial as it indicates the proper temperature at which to mix the binder with aggregate, and compact it on the road surface (Rossmann Sanral, Sabita .T.M. Gilbert, J.A. Grobler, 2002). When the binder is subjected to a temperature above its softening point and is loaded, rutting occurs, and if it is subjected to a temperature below its fragility point, cracking may occur.

The above mentioned properties of bitumen are greatly affected by adverse weather conditions once the bituminous mixture has been laid on the road surface. Bitumen can be modified to enhance their physical properties making it a better binder. From previous research, modified bitumen improves the performances of bituminous mixture and substantially increases the service life of a highway. Once admixtures are added to the conventional bitumen as a modifier, they alter various bitumen properties, making it more stable and stiffer at high temperatures and more flexible at low temperatures (Al-Mansob et al., 2014).

Table 2.1 shows the bitumen properties for conventional bitumen grade 60/70 and grade 80/100 as derived from the different standard manuals. When the bitumen was modified, parameters like penetration grade, softening point, and ductility were tested.

Any binder sample whose penetration value was not with 60-70mm was discarded and briquette prepared using the adopted samples.

Table 2.1 Bitumen Standard Properties

Properties	Grade 60/70	Grade 80/100	Test Method
Penetration at 250° C	60/70	80/100	**IS:1203-1978**
Softening point (R&B) °C	52/60	42/52	**IS:1205-1978**
Ductility @270°C, cm	100	100	**IS:1208-1979**
Specific gravity of bitumen	1.00/1.05	1.01/1.06	**IS:1202-1980**

2.1.2 Modified Bitumen

Investigations have revealed that properties of bitumen and bituminous mixes can be improved, by improving bitumen physical properties without changing its chemical nature (Al-Mansob et al., 2014). In the past, Conventional bitumen used to be modified using agents like polymer, crumb rubber, sulphur, magnesium and polyphosphoric acid (Tam & Tam, 2006). Also cement or lime could be incorporated in bitumen to enhance its adhesive property thus improving the binder strength and its resistance to water damage (C.A. Emeritus, 2002). When approximately 1-2% of lime or cement by mass of aggregate was added to the bitumen, a chemical reaction took place resulting in formation of compounds that were absorbed by negatively charged aggregate surface and this improved adhesion and rendered the aggregates less vulnerable to stripping (B.L Gupta, 2010).

Plastic bags due to their binding properties when molten can be mixed with bitumen to enhance its binding property making it a good modifier (Verma, 2008). Due to its higher softening point, shredded waste plastics bags generally increases the softening point of modified bitumen (Vasudevan, A. Ramalinga Chandra Sekar, B. Sunkarakannan, 2011). Flexibility of the road surface is retained during the cold weather enabling it to withstand repeated loading on warm weather condition resulting in its long life. If cracks development was minimized, the rate of water seepage through the pavement surface is greatly reduced eliminating the effect of water to the underlying layers. In the long run, the serviceability of the road surface is maintained. The environment is improvement by finding a disposal route for plastic bags and job creation (Shirish N. Nemade, 2014). The strength of bituminous mix is improved (Kadam, 2014).

The SWPB particles sizes were limited to only those particles that were retained in sieve size 2.36mm (Verma, 2008). Based on ASTM 2002, where particles size of crumb rubber used in modification of bitumen were limited to particle sizes retained in sieve size 1.18mm and passing through sieve size 4.75mm. In line with, the waste particle sizes to be used in this study will be limited to particle sizes passing through sieve 2.36mm. This will assist in blending the binder homogeneously.

Though SWPB had been used in the past for the modification of bitumen in other countries, the same has not be done locally. This study will aim at testing the locally generated SWPB and further compare its results with those obtained when WSCA is used as a modifier.

These among many other studies, clearly indicate that modified bitumen has been used in the construction of bituminous roads to improve road performance by enhancing bitumen mechanical properties. The studies carried out are not exhaustive and more studies can be done depending on the additives being used in line with sustainable development. According to (Gro Harlem Brundtland, Mansour Khalid, Susanna Agnelli, 1987) in their Brundtland Commission, they defined sustainable development as that development that meets the needs of the current generation without compromising the ability of future generations to meet their own needs. When bitumen is modified, their properties are improved; the rate of extraction will be minimized thus taking care of the future generation.

2.1.3 The bitumen Test

Bitumen is subjected to various tests before it is used as a binder in road construction to determine its suitability as a binding material. The tests include penetration test and this is the measure of hardness or softness of bitumen by measuring the depth a standard loaded needle penetrate vertically in five seconds (Ehinola, Felode, & Jonathan, 2012). Higher penetration values indicate softer consistency while lower values indicate hard consistency. Modification of bitumen tends to lower the value of penetration index. This implies that, soft bitumen can be modified and used as harder binder in a hotter climatic condition.

Secondly, the ring and ball softening point test is a test conducted to determine the consistency of bitumen by measuring the equi-viscous temperature at the beginning of the fluidity range of bitumen (Lesueur, 2009). Generally, higher softening point indicates lower temperature susceptibility and is preferable in hot climates. (Whiteoak D., 1990).

Thirdly, ductility is the distance in centimeters, to which a standard sample of bitumen will be elongated without breaking (Whiteoak D., 1990). This property of bitumen enables it to withstand deformation once a load is applied on its surface. The bituminous surface elongates once subjected to a loading without cracking and consequently protecting the underlying layers to environmental conditions.

The specific gravity of bitumen is the ratio of mass of given volume of bitumen to the mass of equal volume of water at 27^o C and it varies between 0.97 to 1.02 (1202-1978, n.d.). It is measured using either pycnometer or by preparing a cube specimen of bitumen in solid or semi-solid state.

Finally, the Marshall Stability was used to determine the volumetric properties of bituminous mixture to produce a mix with desired properties (Roberts F.L, Kandhal. P.S, Brown. E.Ray, Lee. D, 1991). These volumetric properties include bulk density, voids in mineral aggregates (VMA), voids filled with bitumen (VFB), flow and Stability value.

2.2 The Road Wearing Course Materials

This is the layer in direct contact with traffic loading. It is meant to take the brunt of traffic wear and can be removed and replaced as it gets worn away. The road surface is made up of a mixture of various selected aggregates bound together with bituminous binder, known as Hot Bituminous Mixture (HBM) (Rogers, 2003). The aggregates act as the skeleton while the bitumen provides the muscles to hold it together (Syamsul Arifin, Mary Selintung, 2015). The skeleton must carry the weight while the muscles must be strong enough to hold the skeleton in place but still be flexible enough; this is known as mix design. Mix design is the proportion of the aggregates to be used and the amount of bitumen to be added. These proportions are established by testing various combinations in the laboratory until one is found that meets the desired requirement through Marshall Stability.

A bituminous mixture derives its strength from the cohesion resistance of the binder and the grain interlock and frictional resistance of the aggregate (Aziz et al., 2006). The cohesion resistance is only fully available if a good bond exists between the binder and the aggregates.

2.2.1 Aggregates and their suitability in road construction.

Aggregates constitute a large portion of the materials used in the construction of the road surface. The physical and chemical characteristics of the aggregate play a significant factor in determining the strength of the bitumen and aggregate bond. The aggregates are tested for engineering properties to assess their suitability as road construction materials. Various tests on aggregates have been formulated keeping in view the following quality parameters.

2.2.1.1 Strength

The aggregates which are in direct contact with the traffic load need to be the strongest, compared to those of the subsequent layers (Chakroborty & Das, 2003). A study carried out by (Shagoti, 2015)showed that there is a direct relationship between strength of the aggregates and laboratory permanent deformation properties of bituminous mixture. When the percentage of the crushed particles increases, the rutting of the mixture goes high. When the aggregates are weak, the integrity of the pavement structure will be adversely affected as the aggregates will crush under traffic loading.

The strength of coarse aggregates is measured by aggregate crushing test (ACV). The aggregates crushing test gives a relative measure of the resistance of aggregates to crushing to compressive stress under a gradually applied load (Mathew, 2007). From (Note, 2002), the ACV should not exceed 25%.

2.2.1.2 Hardness

The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving vehicles causing them to undergo continuous wear and tear under the wheels of the vehicles (Chakroborty & Das, 2003). Hard aggregates are better as they have the ability to resist the abrasive effects of traffic over a long time compared to flaky and soft aggregates. The hardness of aggregates is determined by carrying out the Los Angeles Abrasion test (LAA). The LAA test is a measure of degradation of mineral aggregates of standard grading resulting from abrasion, impact and grinding in a rotating steel drum containing a specified numbers of steel spheres (IS 2386 part-IV, 1963). The LAA value should not exceed 25% (Note, 2002).

2.2.1.3 Shape of aggregates

Particles shape and size has a noticeable effect upon the physical properties of bituminous mixture affecting its serviceability (Roberts F.L, Kandhal. P.S, Brown. E.Ray, Lee. D, 1991). Flat and elongated particles tend to break during mixing, compaction, and under traffic making aggregate shape an important factor to be considered to avoid premature pavement failure. There is a direct relationship between rutting of the bituminous mixture and the shape of coarse aggregate particles (N.C Krutz, 1993).

The flakiness index of an aggregate in a sample is found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample. From road note 19 manuals, the flakiness index should not exceed 30% and the test is applicable to aggregates larger than 6.3mm.

2.2.1.4 Adhesion with bitumen

The affinity to water by bituminous pavements construction aggregates should be as minimum as possible. The porosity of aggregates various from one material to the other, and this is determined by the amount of liquid absorbed when aggregates is soaked in water. The intent of this test is to eliminate the use of porous, absorptive aggregates to eliminate stripping of bitumen and eliminate excessive absorption of binder by the aggregates (.P & Adiseshu, 2013). From (Note, 2002), water absorption should be determined and its value should not exceed 2% for the aggregates to qualifier as a road construction material.

2.2.1.5 Durability

Durable or sound aggregates should resist the disintegrating actions caused by repeated cycles of wetting and drying, or change in temperature and this resistance is determined by sulphate soundness testing in the laboratory (Egesi & Tse, 2012). This is accomplished by repeated immersion of weighed aggregate sample in saturated solutions of sodium sulphate followed by oven drying, to dehydrate the salt precipitated in permeable pores spaces for a period of five days. Normally, the aggregates are subjected to the physical and chemical action in the environment demanding that the aggregates used in the construction be sound enough to withstand the weathering action (Clark et al., n.d.). From the (Note, 2002), the Sodium Sulphate Soundness Test (SSS) should be conducted and its value should not exceed 12% for the aggregate to be classified as a durable material (Note, 2002).

2.2.1.6 Freedom from deleterious particles

Aggregates used in road construction should be free from adherent silt size and clay size material as its strength is compromised. It is important to use coarse aggregates as they consume less bitumen compared to fine ones and tend to withstand heavier load (B.L Gupta, 2010).

2.2.1.7 Specific gravity

The specific gravity of aggregates indicates the strength or quality of the material. A higher specific gravity value generally implies a stronger aggregate and vice versa and the values ranges between 2.5 to 2.9 ((1963), n.d.).

2.2.1.8 Aggregate Impact Value (AIV)

Traffic loading on the road surface due to movement of vehicles causes aggregate to break into smaller pieces. This breakage alters the aggregates gradation, widening the gap between properties of the laboratory designed mix and field produced mix finally causing construction and performance problems (Wu, Parker, & Kandhal, 1998). The aggregates should therefore have sufficient toughness to resist breakages due to vehicle impact. This breakage characteristic is measured by impact value test (AIV) and should not exceed 30% (Note, 2002).

2.2.1.9 Sieve Analysis

The purpose of sieve analysis is for determining the percentages of various sizes of minerals aggregates to use to get a mix of maximum density (Chakroborty & Das, 2003). The particle size distribution of aggregates is usually determined and specified by passing aggregates through various sieve sizes and that reveals the size makeup of aggregates from the largest to the smallest. For hot bituminous mixture design and analysis, an aggregates sieve analysis uses the following standard sieve sizes: 37.5 mm, 25.0 mm, 19.0 mm, 12.5 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18mm, 0.60mm, 0.30 mm, 0.15mm, and 0.075 mm among others (Clark et al., n.d.).

The strength and the performance of a bituminous mixture are dependent to a greater extent on the composition of aggregates used. Aggregates used in bituminous paving mixture as coarse, fine and as mineral filler (AL-Saffar, 2013). The main purpose of coarse aggregates is in contributing to the stability of a bituminous paving mixture due to the interlocking and frictional resistance to the adjacent particles, while fines and mineral fillers, fills the voids between the course aggregates (Clark et al., n.d.). Good aggregates selection through gradation is important as this assist in achieving high bulk density, high physical stability, and low permeability (Mamlouk & Zaniewski, 2011).

The results of an aggregate sieving analysis in bituminous mixture technology are usually presented as weight percent passing (Clark et al., n.d.). In this study, three types of aggregates were passed through different sizes of sieves. They included aggregates size 10/14, 6/10 and 0/6 representing coarse aggregates, fine and mineral fillers respectively, all from Aristocrat quarry in Mlolongo.

It is important to note that a good bituminous pavement requires good bitumen, aggregates and equipment and also requires knowledge, skill, and workmanship. Part of this knowledge and skill is the ability to blend aggregates to meet a specific mix, known as the job-mix formula achieved through trial and error methods (Mathew, 2007). The aggregates proportion is varied by varying their percentages and a graph is drawn to determine the kind of blend to be used in preparing the bituminous mixture.

2.3 Re-cycling of waste plastic bags in Kenya

Plenty of plastics bags are manufactured in Kenya today by approximately seventy industries spread out throughout the country and most of these bags are used for shopping, packaging and as trash can liners (Eunice Muchane and Grace Muchane (2006), n.d.). Over twenty-four million plastics bags are used monthly in Kenya, half of which end up in the solid waste main stream (Ong'unya Raphael Odhiambo, Aurah Cathrine Musalagani & Ruth, 2014). The expansion of plastic production and consumption is having a major impact, both visibly and invisibly on the social-physical environment in Kenya (M.M. Ikiara, A.M. Karanja, 2004). Due to ease of accessibility and affordability of plastic bags, the waste generated increases by the day contributing to the blockage of sewer, landfills and adding to the expanding amount of solid waste creating a menace in the environment.

The need to tackle this menace has been high with companies mushrooming in this country engaging in plastic bags recycling. Some of these companies include Nairobi Plastics, Central Glass, Kamongo Waste Paper, Madhu Paper, and Premier Rolling Mills among others (Verma, 2008). Despite the effort by these private organizations, rampant littering is still experienced and additional methods should be introduced to reduce the pollution of the environment by plastics bags.

2.4 Waste Sugar Cane Ash (WSCA)

Researchers have focused their studies on the utilization of industrial and agricultural waste produced by industrial processes focusing on economic, environmental, and technical reasons so as to minimize their effect on the environment. Waste material such as rice husk ash, wheat straw ash, hazel nutshell and sugarcane bagasse ash (referred here as Waste Sugar Cane Ash) are used as construction material for the development of concrete due to their pozzalanic properties (Ganesan K, Rajagopal K, 2007). Sugarcane is a major crop grown in many countries in the world for the production of sugar through processing it in sugar mills that generates millions of tonnes of sugar cane ash as a waste material.

About 40-45% of fibrous residue is obtained after extraction of all economical sugar from sugarcane, and later reused as fuel in boilers for heat generation leaving behind approximately 8 -10 % of ash as waste (H. Otuoze, Y.Amartey, B. Sada, H.Ahmed, 2012). The WSCA has no other economic value and can only be dumped in the open field and this poses a serious threat of polluting air and water bodies and landfills (R, B, & Pradeep T, 2012).

In Kenya, Mumias Sugar Company have boilers that have a capacity of burning 70 tonnes of bagasse per hour with a weekly ash output of approximately 120 tonnes when running at full capacity (Mwero *et al*, 2011). This waste product is non-biodegradable solid material currently being disposed as soil fertilizer though this is not environmentally sustainable (Schettino & Holanda, 2015). Water has to be added to the ash to avoid wind blowing it around thus causing environmental hazard. This calls for urgent ways of handling the waste as it is becoming a menace.

Srinivasan and (Srinivasan & Sathiya, 2010) carried a study on partial replacement of cement with Sugar Cane Baggase Ash (SCBA) and concluded that SCBA improves the quality of construction material such as concrete blocks, mortar, and soil cement interlocking block and thus reducing their production cost. Also the compressive strength of blocks is improved ((Dhengare, Raut, Bandwal, & Khangan, 2015), (Anand & Mishra, 2016) and workability of fresh concrete was improved (Anand & Mishra, 2016).

Typical fillers are fine powder in nature with particle size of less than 75μm and they include industrial waste such as fly ash or natural occurring products like cement, stone dust or calcium carbonate. Filler modify a material by the manner in which it gets distributed in a liquid and how it interacts with the liquid phase of the mixture (Mohi et al., 2015). This interaction creates a chemical bond or physical interaction leading to a reinforced material strength.

Ishfaq and Supriya (2015) carried out a study on the influence of fillers on paving grade bitumen using cement, fly ash and stone dust. The stability value of bitumen was found to improve with cement giving the highest stability value. This could be attributed to the fact that, the fillers tend to fill the voids in the aggregates and also improved the resistance of pavement to permanent deformation. Konstantin *et al* (2013) investigated on the effect of fly ash on bituminous mixture and concluded that fly ash improved the rheological properties of bitumen, its ageing resistance and consequently increasing the longevity of a pavement.

WSCA has pozzolanic properties comparable to Ordinary Portland Cement (OPC) and can have particles size comparable to filler material making it suitable as an additive in bituminous mixtures. The Utilization of WSCA as bitumen modifier may improve the properties of bitumen and minimize the negative environmental effects with its disposal.

2.5 Summary of Gaps in Reviewed Literature

From the literature review, it has emerged that the modification of bitumen has been studied for a number of years since 1970s though they have concentrated mostly on bitumen modification using polymers (Zhu *et al*, 2014). While scholars in developed countries like India, USA, and Arabian Countries have researched on modified bitumen, none or very little has been carried out locally.

During the review of the literature, it is apparent that there are no studies which has been conducted in the area of bitumen modification using Waste Sugar Cane Ash. Bitumen has been modified mostly by the use of polymers such as plastomers (for example, polyethylene (PE), polypropylene (PP), ethylene-vinyl acetate (EVA), ethylene-butyl acrylate (EBA)) and thermoplastic elastomers (for example, styrene-butadiene-styrene (SBS), styrene-isoprene-styrene (SIS), and styreneethylene/butylene-styrene (SEBS) (Polacco *et al*, 2005; Shirish *et al,* 2014; Tapase *et al,* 2014; and Tariq *et al,* 2014). Due to the successes achieved by binder modified by polymer, researchers has paid little interest on the modification of bitumen by other additives. Other additives that have been used to modify bitumen include sulphur, magnesium and crumb rubber among others (Vivian and Tam, 2006).

This research is intended to address that gap by introducing WSCA as a bitumen modifier. SWPB that has been used widely in other countries as a bitumen modifier, will be used to generate results that will be comparable to WSCA. Unlike Verma, 2008 whose study concentrated on modification of bitumen using SWPB whose particles sizes used were retained in sieve 2.36mm. The particle sizes will be limited to only those that will pass through sieve 2.36mm for both SWPB and WSCA. It will assist the investigator have the same comparable particle sizes for both SWPB and WSCA.

The modified bitumen together with tested aggregates were used to prepare briquette and determine their volumetric properties. This is the first study that has focused on the use of WSCA and a blend of WSCA and SWPB as a modifier of conventional bitumen

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this chapter, the details of research work and the procedure of how this study was carried out is explained. Before proceeding to the procedures of laboratory tests, desktop study was carried out to explore the background information of the study. The aim of the research was to assess the physical properties of modified bitumen binder in Hot Bituminous Mixture (HBM) design. Tests were conducted according to the required specifications, laboratory test procedures and information on the materials used. The sample mix tested involved three types of modified bitumen with shredded waste plastic bags, waste sugar cane ash and a blend of the two wastes. The standard bitumen tests were used to determine the properties of modified bitumen while Marshall Stability was used to determine the volumetric properties of the bituminous mixture.

3.2 Research Design

The study was conducted based on laboratory tests as a main procedure to obtain data sets and results. All the tests were conducted using the facilities available in the University of Nairobi Transportation Laboratory and Ministry of Roads bituminous laboratory. The laboratory tests were divided into several stages beginning with sieving of WSCA and SWPB to remove any unburned materials and any material retained in sieve 2.36mm respectively, testing of conventional bitumen, modified bitumen and aggregate preparation. Sieving analysis was carried out to separate aggregate into different sizes. Marshall Stability test method was used to determine the strength of the mix, determine the optimum bitumen content, and other parameters

3.3 Material Collection

The binder used in this study was grade PEN 80/100 and was bought from the Ministry of Publics works. Aggregates were well blended and were purchased from Aristocrat quarry in Mlolongo.

3.3.1 Shredded Waste Plastic Bags

Study was carried out by using experimental methods to mix the plastic waste in bitumen Figure 3.1 represents the tests conducted.

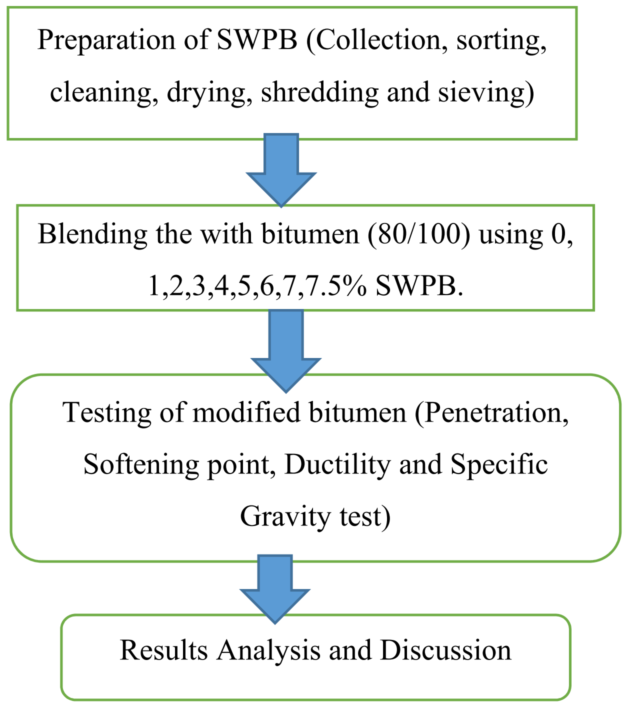

Figure 3:1. Flow Chart of Modification of bitumen with SWPB

Plate 3.1 shows the plastic materials after shredding.

Plate 3.1 Shredded Waste Plastic Bags

3.3.2 Waste Sugar Cane Ash

Figure 3.2 is a flow chart representing modification of bitumen with WSCA

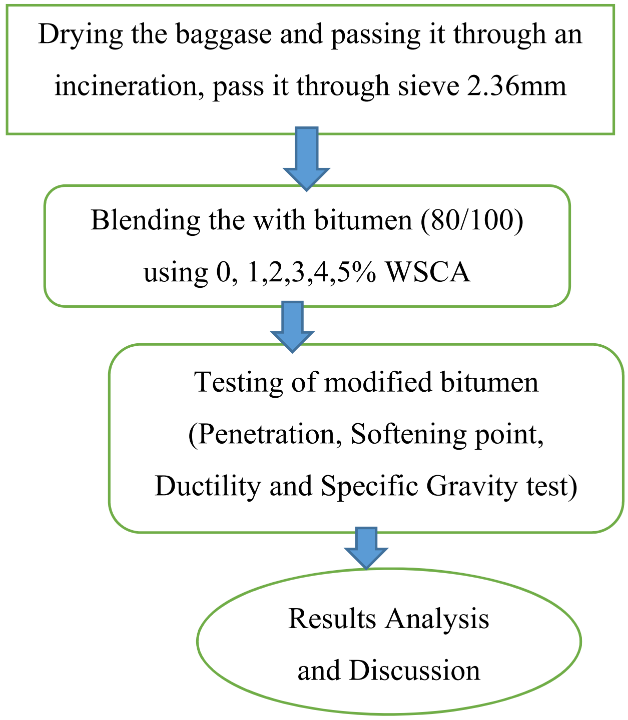

Figure 3:2. Flow Chart of Modification of bitumen with WSCA

Plate 3:2. Waste Sugar Cane Ash

3.4 Material Testing

3.4.1 Sieve Analyses

Single size aggregate size 10/14 and 6/10 were oven dried and their weight taken, while single size aggregate 0/6 were first cleansed to remove all the dust and then oven dried and their weight taken.

A representative sample of the above aggregate was passed through a series of sieves stacked progressively from the top to the bottom as shown in Plate 3.1 and the entire nest agitated. The material whose diameter was smaller than the mesh opening passed through the sieves. After the aggregate reached the bottom pan, the amount of material retained in each sieve was weighed. The results of mechanical analysis were presented by semi-logarithmic plots known as particle-size distribution curves.

Plate 3:3 IS Sieves

3.4.2 Flakiness index (FI)

Flakiness index was determined as per the standard IS 2386-Part 1 -1963.

$$FI = \frac{\text{Passing Sample Particle Count}}{\text{Retained Sample Particle Count + Passing Sample Particle Count}} X100$$

FI should not exceed 35% (John, 2002).

3.4.3 Aggregate Impact Value (AIV)

This test determines the aggregate impact value of coarse aggregates as per IS: 2386 (Part IV) - 1963.

Aggregate impact Value = (W_2/ W_1)× 100

Where W_1 is initial aggregates weight in grams.

W2 is the total weight of the material passing through the 2.36mm sieve.

For aggregates used in construction of wearing course, impact value should not exceed 30%(John, 2002).

3.4.4 Aggregate Abrasion Value (AAV)

This test determines the abrasion value of coarse aggregates as per IS: 2386 (Part IV) – 1963.

AAV = (5000g-W_b)/5000 x 100%

Where W_b is the weight in grams of the crushed material passing through the 1.7mm sieve

Aggregate Abrasion Value should not exceed 30% (John, 2002).

3.4.5 Aggregate Crushing Value (ACV)

The test determines the aggregate crushing value of coarse aggregates as per IS: 2386 (Part IV) - 1963.

ACV = W_2/W_1 x 100%

Where W_1 is the total weight in grams of the dry sample

W_2 is the weight in grams of the aggregates passing through the 2.36mm IS sieve.

The value of ACV should not exceed 25% (John, 2002).

3.4.6 Water Absorption and specific gravity

The test determines the water absorption of coarse aggregates as per IS: 2386 (Part III) – 1963.

$$\text{Specific gravity} = \frac{W_4}{W_3 - (W_1 - W_2)}$$

$$\text{Apparent sp.gravity} = \frac{W_4}{(W_4 - (W_1 - W_2))}$$

$$\text{Water absorption} = \frac{(W_3 - W_4)}{W_4} \times 100$$

Where

Weight of saturated aggregate suspended in water with basket = W_1g

Weight of basket suspended in water = W_2g

Weight of saturated aggregate in water = (W_1-W_2)g = W_sg

Weight of saturated surface dry aggregate in air = W_4g

Weight of water equal to the volume of the aggregate= (W_3-W_s) g

Water absorption value should not exceed 2% (John, 2002).

3.4.7 Sodium Sulphate Soundness Test (SSS)

The test determines the durability of the aggregates as per standard IS-2386-PART-5)

Sodium Sulphate Soundness Test (SSS) = $(W_1-W_2)/W_1 \times 100\%$

Weight of the dry sample = W_1g

Weight of the final sample = W_2g

According to road note 19, the loss in weight should not exceed 10 percent for coarse aggregates and 16% for fine aggregates.

3.5 Bitumen Tests

3.5.1 Modified bitumen

Standard bitumen tests were used to evaluate the quality of modified bitumen and bituminous mixtures. Conventional bitumen was mixed with shredded waste plastic bags, waste sugar cane ash and the blend of the two to form the modified bitumen.

The modified bitumen samples were prepared by adding 1, 2, 3, 4, 5 and 6, 7.5, 10 and 12.5% by weight of the bitumen to different portions of bitumen (Amit, 2013). The SWPB proportions were added to the hot molten bitumen of temperature around 170-180^{o}C by constantly stirring until the mixture was homogeneous and was set aside to cool down.

Based on the above proportions, the waste sugar cane ash was added to conventional bitumen in proportions of 1, 2, 2.5, 3, 4 and 5%.

More bitumen modified samples were prepared by mixing the two waste in different proportions and later mixing them with conventional bitumen. 2.5% WSCA and 1.5% SWPB, 1.5% WSCA and 2.0% SWPB and 2.0% WSCA and 1.0% SWPB by weight of bitumen were added slowly to the molten bitumen until a homogeneous mixture was attained. It is important to note that replacement method was used. For every percent additional of waste, the bitumen quantity was reduced by the same percentage.

Additional of less waste to the bitumen implied a soft blend while higher percentages resulted in a stiffer blend.

The modified bitumen was subjected to a series of standard laboratory tests to determine its physical properties and the results were tabulated. The test that were carried out included: -

i. Penetration test
ii. Ductility test
iii. Softening point test
iv. Specific gravity test

3.5.1.1 Penetration Test

To determine the penetration of bitumen as per IS: 1203 – 1978, the bitumen sample was melted and cooled under controlled condition. A standard needle of a total load of 100g was applied to the surface of the bitumen at a temperature of 25°C for 5 seconds as indicated in Plate 3.2. The amount of penetration of the needle at the end of 5 seconds was measured in units of 0.1mm. The test was conducted three times and average result recorded.

Plate 3:4. Penetration Testing Assembly

3.5.1.2 Ductility Test

In order to determine the ductility of bitumen as per IS: 1203 – 1978, three modified bitumen samples were heated and poured in the mold assembly placed on a plate. These samples with molds were cooled in the air and then in water bath at 27°C temperature. The excess bitumen was cut and the surface was leveled using a hot knife. Then the mold with assembly containing sample was kept in the water bath of the ductility machine for about 90 minutes. The sides of the molds were removed, the clips were hooked on the machine and the machine was operated as shown in Plate 3.3. The distance up to the point of breaking of thread was noted and recorded. An average value for the three samples was calculated and recorded as ductility value of the bitumen sample.

Plate 3:5. Ductility Testing Assembly

3.5.1.3 Ring & Ball Softening Point Test

In determining the softening point of bitumen as per IS: 1203 – 1978, the test was conducted using Ring and Ball apparatus shown in Plate 3.4. A brass ring (weight 3.5 grams) containing test sample of bitumen was suspended in a water bath, in which the bath temperature was raised at 5°C per minute. The temperature at which the ball touched the bottom of the glass container was recorded. The exercise was repeated three times and average result calculated and recorded as the softening point.

Plate 3:6. Ring and Ball Softening Point Test

3.5.1.4 The Marshall Stability of Bituminous Mixtures

The Marshall Stability value of bituminous mixture was estimated as per ASTM D 1559. Approximately 1200g of aggregates was put together as per the determined percentages in the sieve analysis graph and heated to a temperature of 160-170˚C. Aggregates were heated to a temperature of 160˚C with the first trial percentage of bitumen (4.5% by weight of the mineral aggregates). The heated aggregates and bitumen were thoroughly mixed. The mix was placed in a preheated mold and compacted by a hammer having a weight of 4.5 kg and a free fall of 45.7 cm giving 75 blows on either side at a temperature of 160˚C to prepare the laboratory specimens of compacted thickness 63.5+/-3 mm. The briquette prepared are displayed as per Plate 3.5. The height of the samples was measured and specimens were immersed in a water bath. Three samples were prepared for each binder percentage added. The sample weight was taken both in air and in water to determine the bulk density of the sample.

Plate 3:7 Briquette for Marshall Stability Testing

Later, the load was applied to the specimen at a deformation rate of 50.8 mm/minute using Marshall Stability assembly shown in Plate 3.6. The load was increased until it reached a maximum when the load just began to decrease, the loading was stopped and the maximum load was recorded. Flow value was noted as the deformation of the sample at the maximum load. Measured stability values were corrected by multiplying each measured stability value by an appropriated correlation factors as given in the tables in appendices 3

Plate 3:8. Marshall Stability Testing Assembly

After the completion of the stability and flow test, bulk gravity and voids analysis was determined for each test specimen to determine the percentage air voids in mineral aggregate and the percentage air voids in the compacted mix and voids filled with bitumen. Values which were obviously erratic were discarded before averaging. Volumetric parameters such as bulk specific gravity, stability, flow, percentage voids in minerals aggregates (VMA) and Voids filled with binder (VFB) were determined. Graphs were plotted using the obtained parameters separately against the bitumen content and a smooth curve drawn through the plotted values.

3.7 Flow chart of laboratory testing procedure

Figure 3.1 below is a summary of the experimental procedure outlined in this chapter.

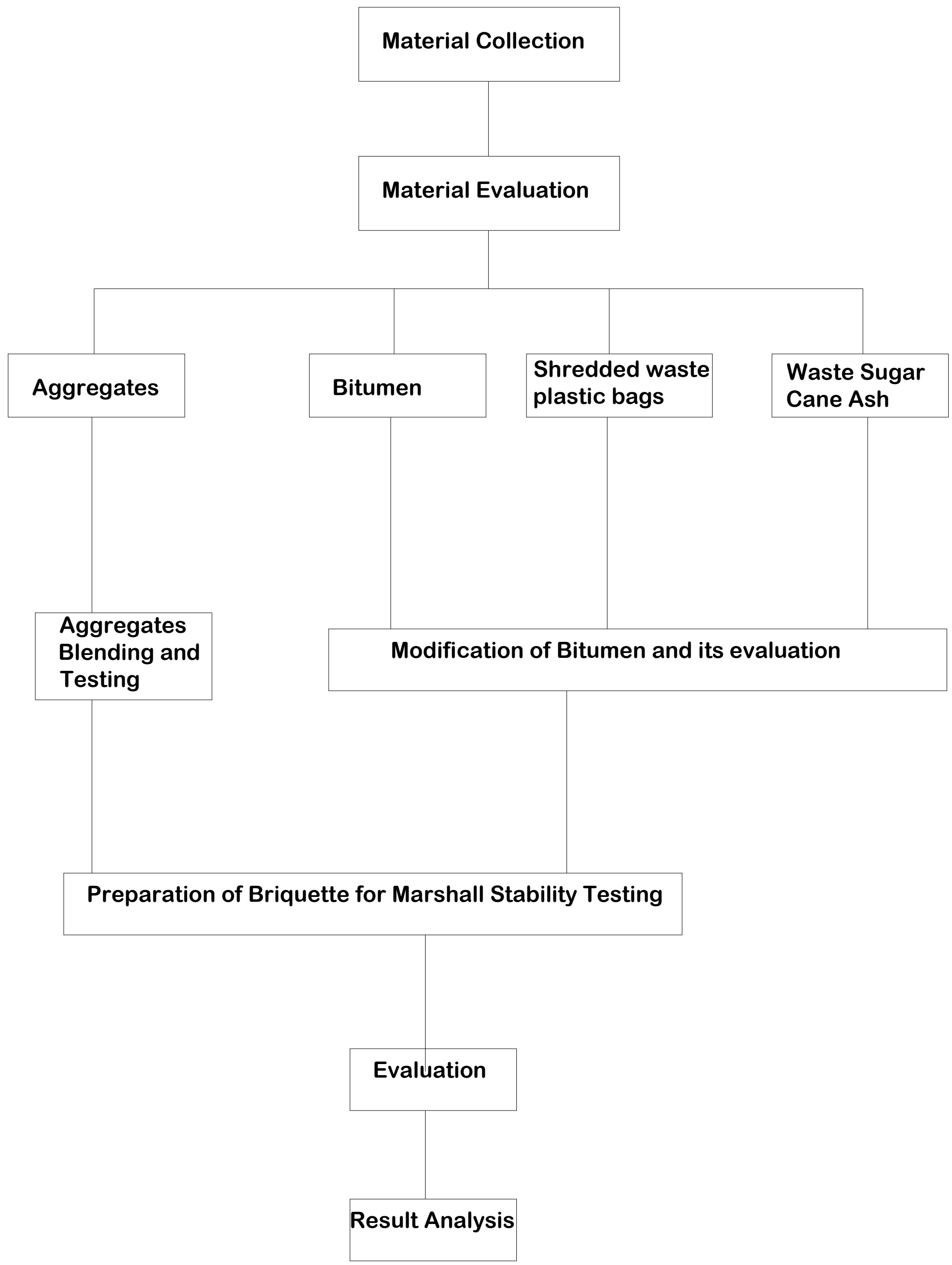

Figure 3:3. Flow Chart of Laboratory Procedure

CHAPTER FOUR

RESULTS ANALYSIS AND DISCUSSION

4.1 Introduction

The chapter discusses the laboratory results for modified bitumen using shredded waste plastic bags, waste sugar cane ash and Marshall Stability test for hot bituminous mixture prepared using the modified binder. The tests were tabulated, necessary graphs drawn and test comparison carried out. The tests determining suitability of aggregates were also summarized in here.

4.2. Sieve Analysis and Aggregates Mix Design Result.

The particle size distribution of all the three types of aggregates was determined through sieving analysis. The cumulative percent passing of the aggregate was found by subtracting the percent retained from one hundred percent. The results for each type of aggregate were then plotted on a different graph with cumulative percent passing on the y-axis and logarithmic sieve size on the x-axis. The results were used to determine compliance of the particle size distribution with applicable specification requirements.

Tables 4.1, 4.2 and 4.3 gives the results for a sieve analysis of aggregates alongside the calculations of percent retained, cumulative percent retained, and percent passing for each aggregate particles are calculated as per the formula: -

$$\% \, Retained \ = \frac{W \ sieve}{Wtotal}$$

Where W_{Sieve} is the weight of aggregate in the sieve

W_{total} is the total weight of the aggregate

$$\% \, Cummulative \ Passing = 100\% - \% \, Cummulative \ Retained$$

$$\% \, Passing = \frac{Wbelow}{Wtotal} X100$$

Where W_{below}- The total mass of the aggregate within the sieves below the current sieve

W_{total}- The total mass of all of the aggregate in the sample.

Table 4.1: Sieve Analysis for Aggregates size 6/10

Weight for the Sample = 615.6g:

Sieve sizes (mm)	**Weight retained (g)**	**Percent Weight Retained**	**Percent Passing**
20	0	0	100
14	0	0	100
10	28.6	4.6	95.4
6.3	319	51.8	43.6
4	268	43.6	0
2	0	0	0
1	0	0	0
0.425	0	0	0

Table 4.2: Sieve Analysis for Aggregates size 10/14

Weight for the Sample = 924.6g

Sieve size (mm)	Weight retained (g)	Percent Retained	Percent Passing
20	0	0	100
14	142.8	15.5	84.6
10	684.8	74.1	10.4
6.3	96.4	10.4	0
4	0	0	0
2	0	0	0
1	0	0	0
0.425	0	0	0

Table 4.3: Sieve Analysis for Aggregates Size 0/6

Weight for the Sample = 817.4g

Sieve sizes (mm)	Weight retained (g)	Percent Weight Retained	Percent Passing
20	0	0	100
14	0	0	100
10	0	0	100
6.3	4.9	0.6	99.4
4	89.1	10.9	88.5
2	143.9	17.6	70.9
1	0	26.4	44.5
0.425	0	16.8	27.7
0.3		5.5	22.2
0.15		5.6	16.6
0.075		2.9	13.7
Less than 0.075		13.7	0

A mix design was carried out through trial and error method to determine the proportions of different aggregates and how they should be mixed together for a strong blend. The mix proportions determined were 55% quarry dust (0/6), 23% size 6/10 aggregates and 22% size 10/14 aggregates and the results are as attached in the appendices one. From the trial and error method carried out, these aggregates have sufficient dust and no more fines to be added to it. This can be deduced from the results attached in the Appendix 1.

The theoretical combined grading (TCG) was determined by combination of the three singles aggregates using the proposed percentages in each sieve size.

$$TCG \ = 55\% \ x\% \ passing \ 0/6 \ + 23\% \ x \ \%passing \ 6/10 \\ + 22\% x \ \% \ passing \ 10/14$$

While actual grading of the aggregates is determined by combining the three single aggregates by weight using the above percentages against 1100g. Then sieving analysis is carried out on the combined aggregates and a graph is drawn to ensure the combined curves passes through the standard maximum and the minimum curve as per Figure 4.1.

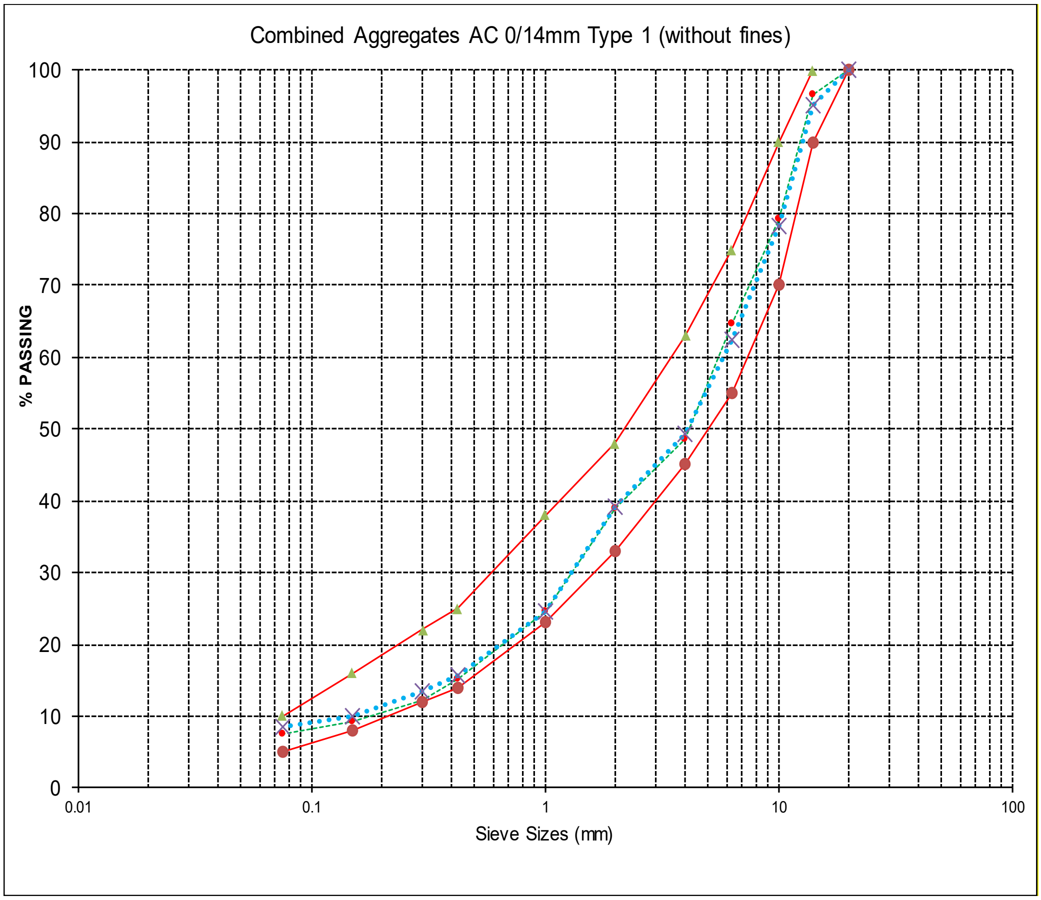

Figure 4:1. Graph of percentage passing of aggregates Vs sieve size (mm)

A particle size distribution analysis was a necessary classification test for aggregates in that it presents the relative portions of different sizes of aggregates. Proper mixing of aggregates is important before being mixed with hot bitumen as it ensures that the right sizes of voids are maintained for adequate covering of aggregates by the binder. Adequate voids in mineral aggregate (VMA) during mix design and in the field, helps in establishing sufficient film thickness without excessive binder bleeding or flushing (Robert, 1991)

The gradation of the aggregates used in this project gave a coarse blend that is economical as it consumes less binder. These aggregates are suitable as road construction material and will not interfere with performance of hot bituminous mixture.

4.3 Aggregates Test Results

The aggregates used in this study were subjected to various aggregates tests to determine their suitability as road construction material. The laboratory results for the various tests are summarized in the Table 4.4. The test analyses are attached in Appendices 3.

Table 4.4: Summary of the Aggregates Test Results

Property of aggregate	Type of Test	Standard	Value	Limitation
Crushing Strength	Aggregate Crushing Value	IS:2386(Part 4)	20.60%	30%
Hardness	Los Angeles Abrasion test	IS:2386(Part 5)	17.10%	35%
Toughness	Aggregate Impact Value	IS:2386(Part 4)	10.10%	30%
Durability	Soundness test	IS:2386(Part 5)	2%	12%
Shape Factor	Flakiness index	IS:2386(Part 1)	9.70%	
Specific Gravity & Porosity	Specific gravity	IS:2386(Part 3)	2.737	
Adhesion of Bitumen	Water absorption	IS 6241-1971	0.691	2%

From the test results tabulated above, it is clear that the aggregates used in this study were within the recommended parameters and thus good for road construction. The purpose of these tests is to ensure the results achieved at the end of the study are not influenced by the aggregates in a negative way.

4.4 Bitumen

Conventional bitumen used in this research was grade 80/100 as is commonly used in construction of bituminous roads in Kenya. The conventional bitumen was taken through the standard bituminous test like penetration test, ductility test, ring and ball softening point test, specific gravity and its results are tabulated in Table 4.5 to ascertain of its properties and compare them with the manufacturer's standard specification as Appendix 1. The importance of the procedure is to ensure the bitumen being modified is pure with no additives. This will assist in establishing the effect of the modifiers on the bitumen. The results were presented in Appendix 2

4.5. Evaluations of mechanical properties of modified binder.

A standard briquette weighs 1200g, consisting of 80g bitumen and 1120g aggregates. The research concentrated in modifying the 80g of bitumen by replacing the weight of the binder by the percentage weight of the additive.

Bitumen was initially modified by blending it with SWPB, using different percentages as indicated in Table 4.5 up to 12.5% of SWPB where the sample became too stiff to be worked on. Workability was one of the factors used in determining the amount of additive to be added to the bitumen as a modifier. The samples were taken through bitumen standard test such as penetration, softening point, ductility, specific gravity test and their results are tabulated as Table 4.5 -:

Table 4.5: Bitumen Modified with SWPB

% Wgt of SWPB	% Wgt of Bitumen	Penetration Value (mm)	Softening point Value (°C)	Ductility Value	Specific gravity value
0	0	87	52	100	1.01
1	99	75	55	49	1.01
2	98	65	57.3	41	1.01
3	97	61	61.4	36	1.02
4	96	55	65.2	23	1.01
5	95	51	66.6	16	1.00
7.5	92.5	20	96	3	
10	90	Very Stiff			
12.5	87.5	Very stiff			

Table 4.6 gives the results of bitumen modified with waste sugar cane Ash (WSCA). In each sample of bitumen, a certain percentage of bitumen was replaced by the same percentage of WSCA and the sample taken through the standard bitumen test. The bitumen could only be replaced with 5% WSCA beyond which the blend became too stiff to be worked on. This could be due to pozzolanic nature of WSCA making it to absorb bitumen when blending and fill the molecular spaces in bitumen, thus making it stiff. Also the amount of bitumen decreases as the mount of modifier increases thus increasing the stiffness of the modified binder.

Table 4.6: Bitumen Modified with WSCA

% Wgt of WSCA	% Wgt of Bitumen	Penetration Value (mm)	Softening point Value (ºC)	Ductility Value	Specific gravity value
0	0	87	53	100	1.01
1	99	78	53	89	1.02
2	98	67	55	68	1.04
2.5	97.5	62	56.6	55	1.05
3	97	58	57.3	34	1.07
4	96	45	58.2	28	1.08
5	95	30	59.8	20	1.09
6	94	Very Stiff			

The different percentages of the WSCA used in modifying bitumen were comparable to percentages of SWPB used in modifying bitumen and the consistency of modified binder and the maximum additives used was 6% due to workability.

Bitumen was also modified using a blend of WSCA and SWPB and the same modification method was used and results tabulated in Table 4.7. Due to workability of the binder, the amount of additives that were used with bitumen were limited to the stated percentages.

Table 4.7: Bitumen Modified with SWPB and WSCA

% Wgt of SWPB	% Wgt of WSCA	% Wgt of Bitumen	Penetration Value (mm)	Softening point Value (°C)	Ductility Value	Specific gravity value
0	0	100	87	52	100	1.01
1.0	1.0	98	72	53	50	1.03
2.0	1.5	96.5	68	57.8	45	1.04
1.0	2.0	97.0	65	54.3	43	1.05
1.5	2.5	96.0	36	55.4	27	1.06
2.0	2.0	96.0	58	59	47	1.07
3.0	3.0	94.0	32	Too stiff		

The mechanical properties of bitumen were altered when bitumen was reduced by certain percentages and mixed with the same percentage of additive. From the samples prepared, bitumen could be replaced by 3% SWPB or 2.5% WSCA and this implies that bitumen as a binder cannot be totally replaced as a road construction material. The properties were discussed as follows: -

4.5.1 Penetration Value

The Penetration Value of the convectional and modified binders are presented in Figure 4.2. They decreased with increase of both Shredded Waste Plastic bags and

Waste Sugar Cane Ash in the bitumen. The penetration value of binder modified with SWPB decreased from 87 to 20mm with increase in SWPB from 0 to 7.5%, while binder modified with WSCA decreased from 87 to 30mm with increase of the additive from 0 to 5%.

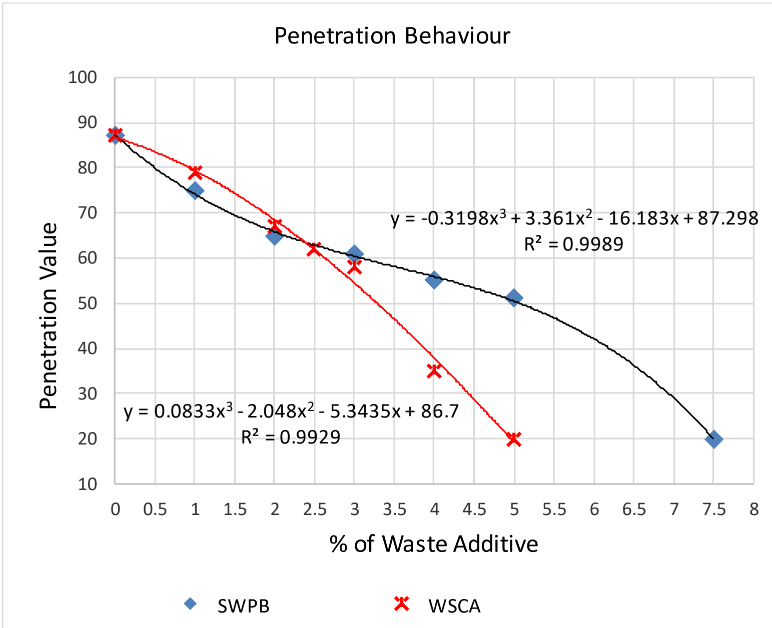

Figure 4:2. Penetration Vs Percent Waste Additive.

The R^2 is 0.9989 (99.89%) and 0.9929 (99.29%) for SWPB and WSCA respectively, thus the line drawn is the best line of fit. There was a sudden drop in the penetration value when 1and 2% of SWPB was added to the bitumen then a gentle drop upon to 5% of the additive then another sudden drop. WSCA curve gave a gentle drop of penetration value. Polynomial equation indicated against each line will assist the investigator predict the behavior of the penetration value with percentage increase of the waste additive.

Binder modified with WSCA were slightly softer than binder modified with SWPB up to 2.25% additive where stiffness increases. This could be due to the increase of impurities in the bitumen hindering the needle from penetrating further into the bitumen. WSCA due to its pozzolanic nature, will absorb bitumen and due to its fineness, mix with bitumen molecules much faster hindering the penetration needle from going further into the binder.

The performance of bitumen can be predicted by its penetration value as it represents its quantitative measure of bitumen in response to temperature. Therefore, bitumen with high penetration value can be referred to as soft and be used for cold climates while those with low values treated as hard are used for warm climates (Nurul *et al*, 2016). When the binder is soft, it will resist cracking at low temperature but undergo deformation under loading at high temperatures and vice versa (Tasdemir, 2009). The waste additive has a great effect on reducing the penetration value by increasing the stiffness of the modified binder. Lowering the penetration values of the binder makes it less susceptible to increase in temperature. The resistance of the binder to deformation is improved.

4.5.2 Softening Point.

The relationship between softening point value of the bitumen and the additive is represented in Figure 4.3. The polynomial equation indicated against each line will assist the investigator predict the change in value of softening point with increase in waste material. The softening point value of the binder increases with increase of both SWPB and WSCA. The softening point value of binder modified with SWPB ranged between 55 to 66.6^{o}C, while that of binder modified with WSCA ranged between 53 to 57.3^{o}C with increase of the additives. Figure 4.3 clearly indicates that the binder modified with SWPB has a higher softening point value than that of binder modified with WSCA. This could be due to higher boiling point of SWPB.

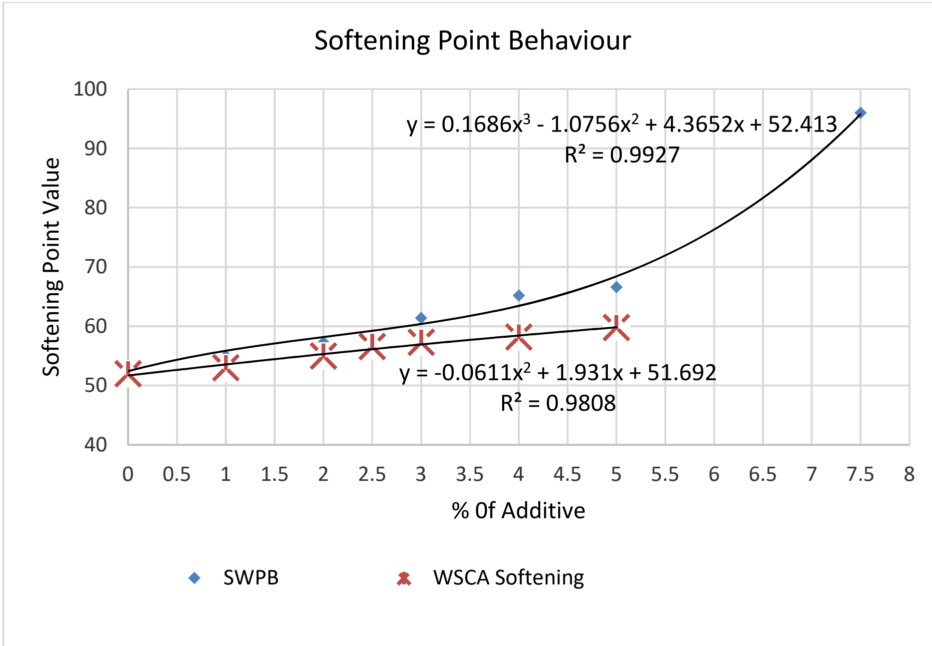

Figure 4:3. Softening Value Vs Percentage Additive.

Both additives increase the softening point of the binder and this phenomenon indicates that the resistance of the binder to the effect of heat is increased and reduces its tendency to soften in hot weather. The main idea of replacing bitumen with waste additive is to modify it so as to increase the resistance of the bituminous mixture to permanent deformation at high road temperature and still retaining the properties of the bitumen or bituminous mixture at other temperature (Poorna and Mohamed, 2014). The modified binder is less susceptible to temperature changes.

4.5.3 Ductility Value

The relationship between the ductility value of the bitumen and modifying additive is represented in Figure 4.4. The polynomial equation indicated against each line will assist the investigator predict the change in value of ductility index with percentage increase in the waste material.

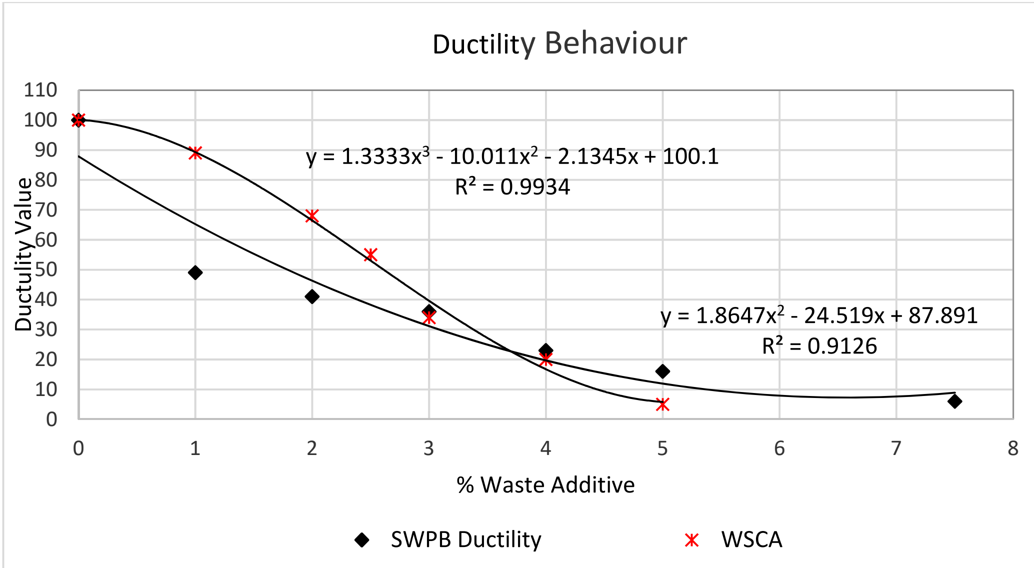

Figure 4:4 Ductility Vs Percentage Waste Additive.

The ductility value decreases with the increase of both SWPB and WSCA. It is very clear that ductility of the binder modified with SWPB decreases between 100 and 16mm, while that modified with WSCA decreases between 100 and 5mm with increase with both additives. The decrease in the ductility value could be due to the interlocking of waste molecules with bitumen. The binder modified with WSCA will stretch more than the one prepared using SWPB up to 3% of waste additive due to the interlocking nature of its molecules. Binder modified with WSCA is more flexible than binder modified with SWPB.

This decrease in ductility value of the binder enables it to stretch less under loading and recovers quickly when the loading has been removed leading to reduction in deformation.

4.5.4 Specific Gravity

The relationship between specific gravity of modified binder and the percentage of waste material added to the bitumen is represented in Figure 4.5. The polynomial equation indicated against each line will assist the investigator predict the change in value of specific gravity with percentage increase of the waste material.

The Specific Gravity of the binder modified with SWPB decreased up to a certain level and then increased with increase with SWPB content while that modified with WSCA increased with increase with WSCA content. According to ASTM standards, the specific gravity of polythene material ranges between 0.910-0.960g/cm^3 while that WSCA was estimated to be 1.2g/cm^3 (Chennakesava and Prabath, 2015). This could be the reason why the values of specific gravity of the binder modified using WSCA are higher than binder modified using SWPB.

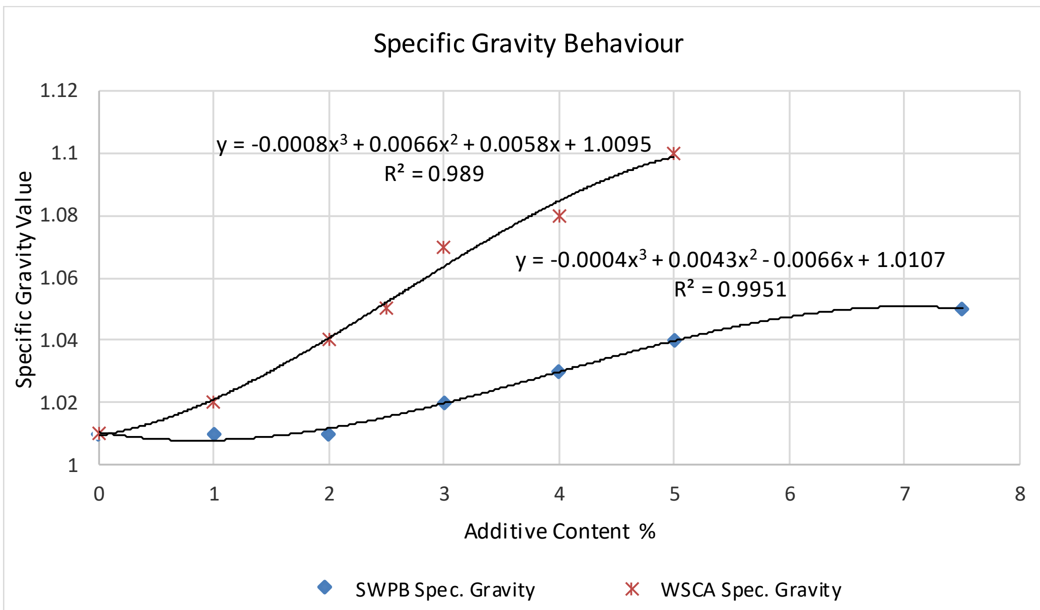

Figure 4:5. Specific Gravity Vs Percentage of Additive

4.5.5 Summary

Seven sample of binder were prepared and tested. One was conventional bitumen while the other six were modified using shredded waste plastic bags, waste sugar cane ash and a blend of the two. The binders whose penetration grade fell within 60 to 70mm were singled out and used in molding briquette for Marshall Stability testing and the results are tabulated in Table 4.8. The other samples were discarded as they were either too soft or too hard for this study.

Table 4:8 Results Summary for Bitumen used in Marshall Stability Test.

% Wgt of SWPB	% Wgt of WSCA	% Wgt of Bitumen	Penetration Value (mm)	Softening point Value (^oC)	Ductility Value	Specific gravity value
Binder samples modified with SWPB						
2	0	98	65	57.3	41	1.01
3	0	97	61	61.4	36	1.02
Binder samples modified with WSCA						
0	2	98	67	55	68	1.04
0	2.5	97.5	62	56.6	55	1.05
Binder Samples modified with the blend of the two additives						
2.0	1.5	96.5	68	57.8	45	1.04
1.0	2.0	97.0	65	54.3	43	1.05

4.6.0 Marshall Stability Test

Marshall Stability tests were conducted on the different briquette and volumetric parameters like flow value, bulk density, voids filled with bitumen (VFB) and voids filled with mineral aggregates (VMA) were analyzed and the results were attached in Appendix 2. The results were converted to standard units using correction ratios in Appendix 4 and the results posted in Appendix 2

4.6.1 Bulk Density.

Figure 4.6 is for bulk density calculated from various briquette prepared using different binders.

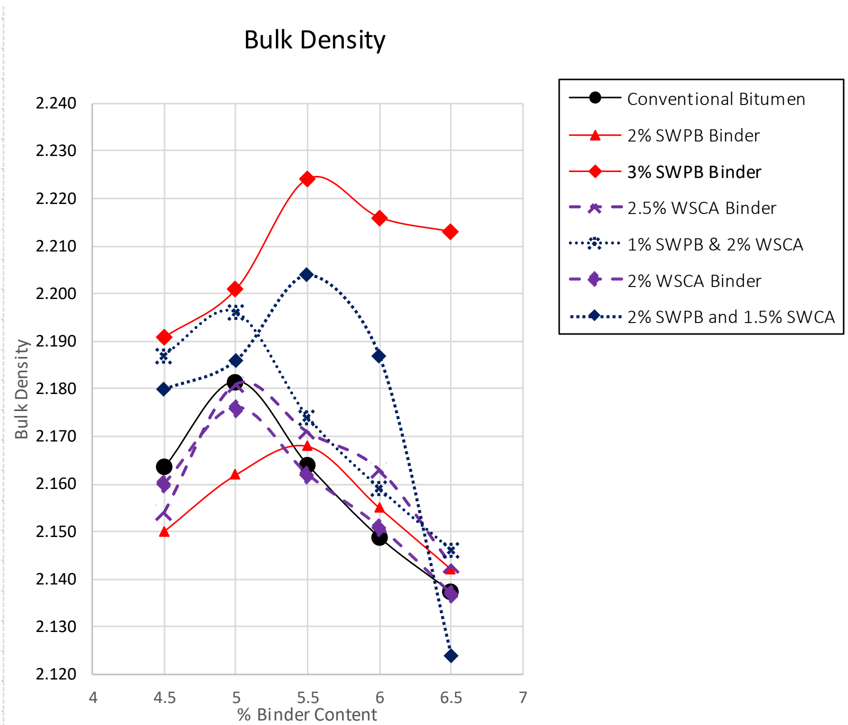

Figure 4:6Bulk Density Vs Percentage Binder Content.

Binders modified using 3% SWPB, a blend of 1% SWPB and 2% WSCA, and a blend of 2% SWPB and 1.5% WSCA yielded highest bulk density value compared to conventional bitumen. While binder modified using 2.5% WSCA, 2% WSCA and 2% SWPB yielded binder with less bulk density value compared to conventional bitumen.

The bulk density of conventional bitumen was affected by additional of waste material by raising it to a certain point then lowering it as the total percentage of the additive increased. This point could be referred to as optimum binder content. The design curves indicated that the optimum binder content was higher when 3% SWPB and a blend of 2% SWPB and 1.5% WSCA were used to modify bitumen which was 5.5% binder content and is higher than that of conventional bitumen and other binders. This could be due to the fact that WSCA being comparable to Portland cement enhances adhesion of bitumen with aggregates.

4.6.2 Marshall Stability and Flow Value

Figure 4.7 represents the effect of shredded waste plastic bags and waste sugar cane ash on the bituminous mixtures. As the additive content increased, the stability value initially increased, reaching a maximum value and then started decreasing.

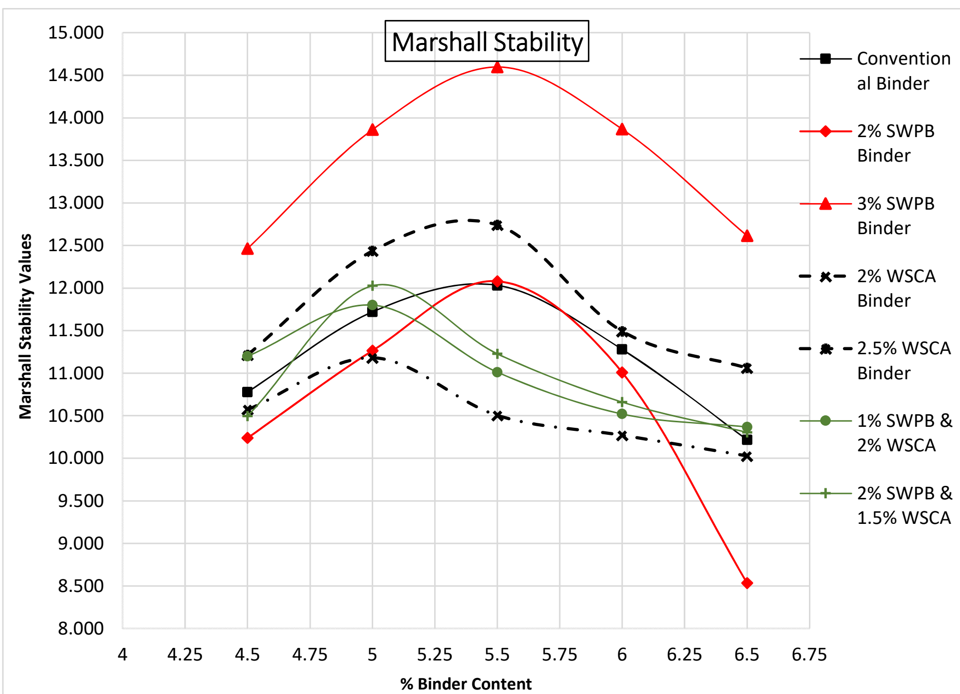

Figure 4:7. Marshall Stability Vs Percentage Binder Content.

Briquette prepared using modified binder of 3% SWPB and 2.5% WSCA yielded the highest Stability value. Additional of 3% SWPB to the bitumen raised the Marshall

Stability value of controlled mix to 14,400N from 11,300N which was equivalent to 27.33 while 2.5% WSCA raised it to 12,600 that is equivalent to 11.5% increase in binder strength. This could be attributed to specific gravity of plastic bags that is less than that of bitumen and is less than one. It enables the binder to penetrate between the aggregates increasing the bond between the binder and the aggregates thus increasing the stability. The optimum binder content was 5.5%, beyond which the stability decreases. This could be caused by too much binder in the mix reducing the interlocking between the binder and the aggregates. From the design graphs, the binder modified with 3% SWPB gave the highest stability value and thus the highest bituminous strength.

Samples prepared using 2.5% waste sugar cane ash gave a higher stability conventional mix but less than that of 3% SWPB. The stability value increased by 11.5% from 11,300N. This could be attributed to the adhesive properties between WSCA and bitumen holding the aggregates more strongly compared to when conventional bitumen is used. The highest strength is obtained at the optimum binder content (OBC) of 5% beyond which the strength of the bituminous mixture start decreasing. This could be attributed to the increase of fines in the mixture due to higher percentage of WSCA absorbing part of the bitumen and interfering with the gradation of aggregates. If all the voids are filled by bitumen, then the load is transmitted by hydrostatic pressure through the binder instead of through contact points of aggregates and the strength of the mix therefore decreases.

It is clear from the Figure 4.7 the blend of the two waste increases the Marshall Stability value of the conventional mix. Blend of 2% SWPB and 1.5% WSCA increased the bituminous mix strength to 12,030N while 1% SWPB and 2% WSCA increased the bituminous mix strength to 11,080N. The higher the percentage of the additive to the bitumen, the better the strength of the bituminous mix.

Figure 4.8 portrays the relationship between the flow value and bitumen content. The flow value of the binder increased with the increase in binder content. The Marshal Flow value was also altered by the additional waste material to conventional bitumen. The flow value increased when WSCA was added to the mix indicating improvement in the resistance to permanent deformation of bituminous mixes. The flow value of the sample prepared using 2 and 3% SWPB, and the blend of the additive was lower than that of conventional binder while the flow value of sample prepared using 2 and 2.5% WSCA is higher.

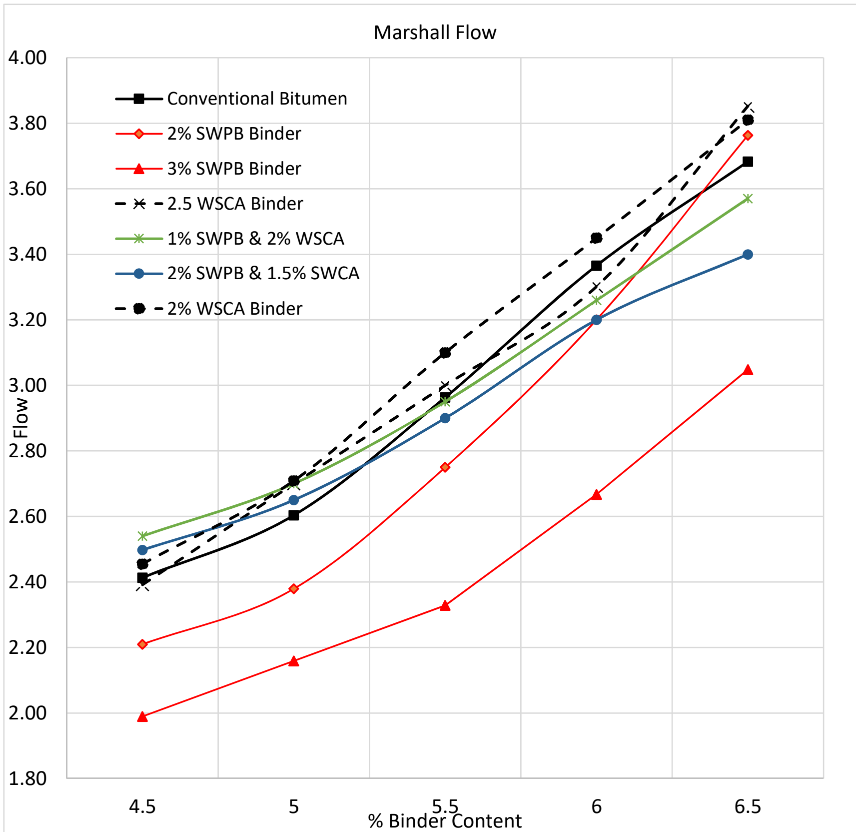

Figure 4:8. Flow Value Vs Percent Binder Content.

4.6.3 Voids in Mineral Aggregates and Voids filled with Bitumen

The total volume of void spaces that exist between the aggregates particles in a compacted bituminous mixture plus those filled with bitumen are referred to as voids in mineral aggregates (Roberts *et al*, 1991). These are the spaces available to accommodate binder once bitumen and aggregates are mixed together and it is expressed as a percentage of the total volume of the mix.

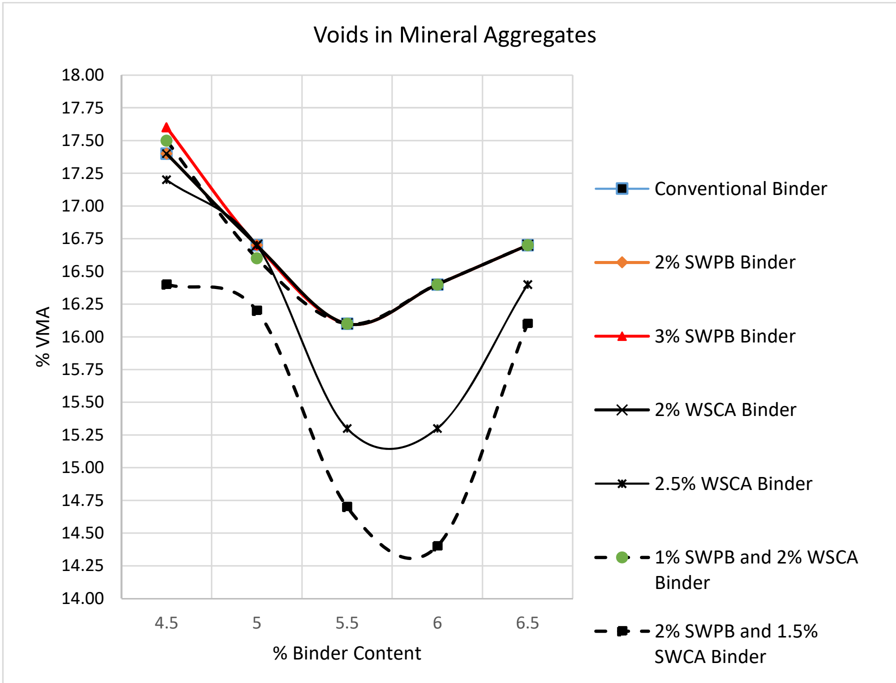

Figure 4:9. VMA Vs Percent Binder Content.

From the Figure 4.9, the design curve for conventional bitumen, 2% SWPB, 3% SWPB, 2% WSCA and 1% SWPB plus 2% WSCA exhibit the same characteristics of Voids in Mineral Aggregates (VMA) while that of 2% WSCA, 2% SWPB and 1.5% SWCA binder has lower values. The VMA value with lower binder content is high, then reduces to a certain point, then start increasing. VMA is inversely proportional to Marshall Stability value of the briquette. When VMA is too low, there is not enough room in the mixture to add sufficient binder to coat the individual particles leading to stripping of aggregates and while it is too higher there will be overfilling of the voids leading to bleeding of the pavement. Adequate VMA is important as it ensure the pavement is durable.

Void filled with bitumen (VFB) is the percentage of VMA containing bituminous binder in the briquette. It refers to the voids that exist between the aggregates particles in the compacted mixture that are filled with binder. The relationship between the VFB and binder content is illustrated by design curves (Figure 4. 10).

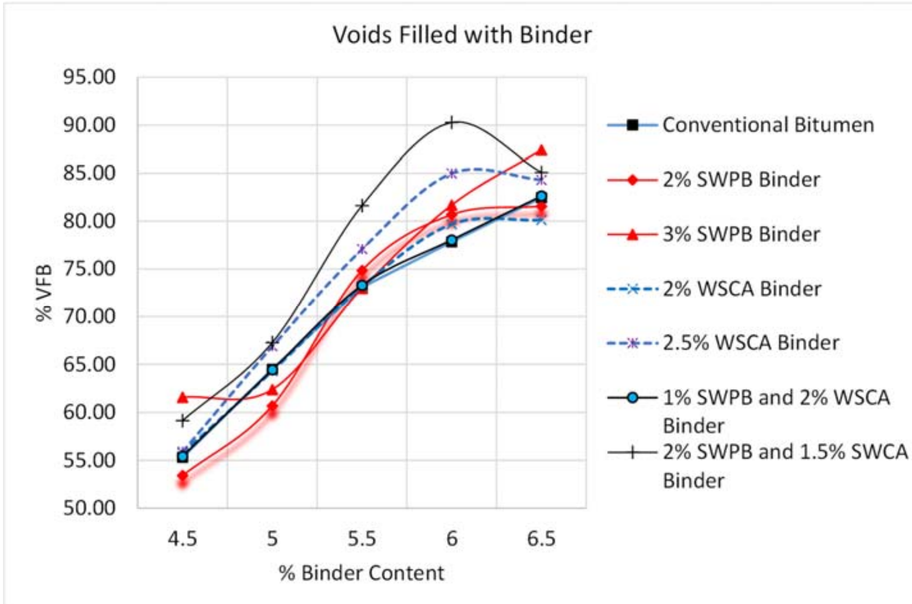

Figure 4:10. VFB Vs Percent Binder Content.

Generally, VFB increases with increase with binder content. The binder modified with SWPB has a higher VFB value than both conventional bitumen and binder modified with WSCA. This could be due to the fact that SWPB has a lower specific gravity enabling it to coat aggregates faster than the other two binders. At OPC of 5.5%, the VFB for all the mix are higher than that of conventional mix. This is facilitated by the ease at which the binder is able to penetrate between the aggregates spaces.

The main effect of VFB is to limit maximum levels of VMA and subsequently maximum levels of binder content. VFB also restricts the allowable air void content for asphalt mixtures that are near the minimum VMA criteria. The VFB is inversely related to the air voids. As the percentage of air voids approaches zero, the VFB approaches a hundred though the binder is expected to fill up between 67 and 75 percent of these voids (Ganapati and Adiseshu, 2014).

Void in the mix (VIM) is the total volume of the small air pockets between the coated aggregates particles throughout the compacted paving mixture. The amount of voids in the mix is very important and closely related to stability, durability and permeability of the bituminous mixture. Insufficient air voids content can lead to flushing, in which excess bitumen squeezes out the mix to the surface. Excessive of air voids content in the mix provides passageways through the mix for water and air, damaging the pavement layer (Roberts, 1991).

The relationship between VIM and binder content is illustrated in Figure 4.11. The percentage of VIM decreases exponentially with increase with binder content. VIM is highest in samples prepared using binder modified with SWPB. However, the VIM of all samples prepared using different binder content are located within the specification range of 3 to 5% (John, 2002) which support the use of these additive.

VMA and VFB are widely accepted that these volumetric properties are useful in predicting hot mix bituminous pavement performance. Excessive air or inadequate VMA brings about durability problem leading to rutting of the bituminous surface.

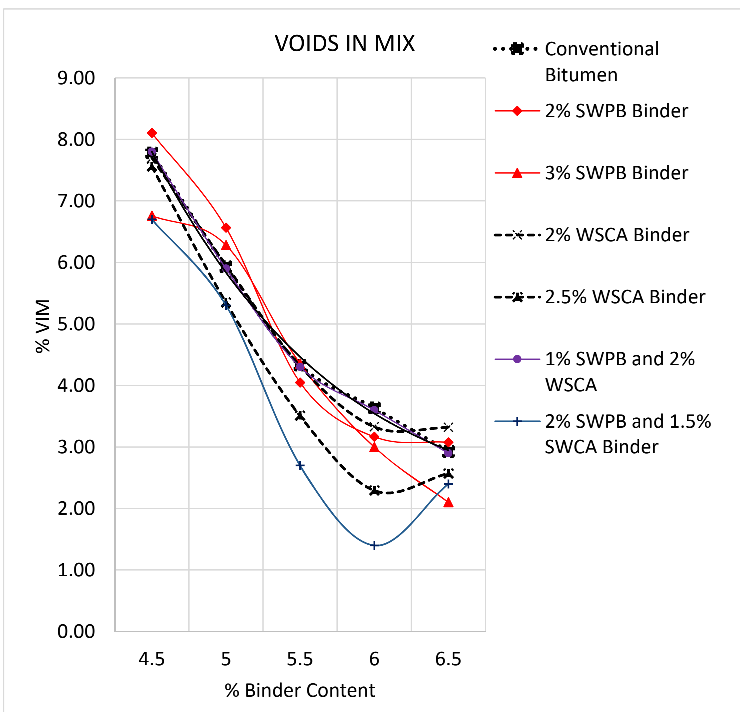

Figure 4:11. VIM Vs Percent Binder Content.

4.7 Cost Analysis for surfacing for 1Km stretch using modified bitumen

Assuming a 50mm thick wearing course is to be laid on a proposed construction of a one kilometer stretch of road, 1m wide using modified bitumen. The cost saving determination for the purposes of this study is done using 3% SWPB and 2.5% WSCA as they gave the highest stability value when briquettes were prepared. Cost analysis will be laid out as per Table 4.9.

Table 4:9. Cost Analysis Determination.

SERIAL NO.	DESCRIPTION	QUANTITY
1	Bitumen required for 50 mm thick wearing course (WC)	1,825.0Kgs
2	Bitumen required for premix concrete (PC)	5,256.0kgs
3	Bitumen required for seal coat (80/100 Grade)	2,803.2kgs
4	Total bitumen quantity	11,703.2kgs
5	Total bitumen required in WC and PC	7,081.0 Kg
6	Total SWPB 3% (i.e. 3.75% of total bitumen required in WC & PC)	265.54kgs.
7	Quantity of Bitumen required in WC & PC after the addition of SWPB	7081-265.54 = 6,815.46
8	Total quantity of bitumen saved using SWPB	265.54kgs
9	Total cost of the project (1 kgs @200)	7081x200 = 1,416,200/=
10	Final cost of project	6815.46kgs x 200 = 1,363,092/=
11	Total Saving	265.54kgs x 200 = 53,108/=

When 2.5% WSCA was used as a bitumen modifier, the amount of bitumen saved will be equivalent to 3.125% of 7081 = 221.28kgs @ 200/ = 44,256/=

There was a cost reduction of 53,108/= for one kilometer stretch of the road when 3% shredded waste plastic bags and 44,256/= when 2.5% WSCA were used to modify bitumen respectively. Though the reduction in cost may seem little, the binder will provide a more stable durable mix for the flexible pavement. The modified bitumen used in designed mix for pavement construction will have strong, durable and ecofriendly road which will relieve the earth from all types of non-biodegradable waste.

Table 4.10: Summary of Marshall Stability Results

	Neat Bitumen	2% SWPB	3% SWPB	2% Ash	2.5% Ash	2.5% SWPB+ 1.5% Ash	1% SWPB +2% Ash	Std Specification
Optimum Binder Contents %	5.5	5.5	5.6	5.4	5.4	5.4	5.4	5.0-6.5
Stability Value Kn	11.3	12.2	14.4	11.5	12.6	11.6	11.5	9.0-18.0
Flow Value	3.4	2.8	2.9	2.8	2.3	3.4	2.9	2-4
Voids in Mix	4.7	5.0	4.5	5.0	4.75	4.7	4.8	3-5
Voids filled with Bitumen	16.4	16.4	16.3	16.4	16.3	16.6	16.3	
Voids in Mineral Aggregates	72	70	70	73	72	72	72	65-75

Bituminous mixture results obtained in this study were within the standard specifications (Table 4.10). The bituminous mix prepared using binder modified with shredded waste plastic, waste sugar cane ash and the blend of the two additives is superior to that prepared using conventional bitumen. The Marshall Stability value was high while flow value and optimum binder content was lower compared to the conventional one.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following are conclusions that could be drawn based on the results of this research.

1. The mechanical properties of conventional bitumen were altered when shredded waste plastic bags, waste sugar cane ash and the blend of both waste materials when added to it as a modifier. The penetration value of binder decreased from 87 to 20mm while ductility value decreased from 100 to 3cm with increase in percentage of waste replacement. The Softening point of the binder increased from 52 to 96^{o}C with increase with waste addition. This alteration of the mechanical properties of the bitumen aids in improving the road surface performance by increasing its resistance to wear and tear and deformation.

   The modified bitumen with 2 & 3% SWPB, 2 & 2.5% WSCA, the blend of 2% SWPB & 1% WSCA and a blend of SWPB & 2% WSCA were narrowed down to as the best binders as their penetration values were within those of bitumen 60/70. Though the parameters of binder modified with 2.5% WSCA by weight of bitumen were all within the standard specification of bitumen grade 60/70 apart from its ductility value of 55cm that is lower than the recommended ductility of 100cm, it can be treated as the optimum mix.

2. There was a considerable increase in Marshall Stability value ranging from 11450N to 14400N and reduction in flow value varying from 3.4 to 2.3mm depending on the binder used. With increase in Marshall Stability and reduction in flow, the formation of rutting, potholing and cracks will be greatly reduced. This improves the performance of the road surface by reducing the formation of rutting, potholing and cracking.

   The binder modified with 3% SWPB and 2.5% WSCA gave the highest stability value. However, the WSCA produced the better results at optimum mix of 2.5% SWPB and 97.5% bitumen by weight compared to optimum mix blend of SWPB and WSCA binder due to its higher ductility value and low flow value. The improvement of bituminous mix of WSCA gives the best results.

3. There would be a slight cost benefit of approximately KES. 53,108/= and KES 44,256/= when SWPB and WSCA are used to modify bitumen respectively. This is in additional to many environmental benefits.

5.2 Recommendations.

5.2.1 Recommendations.

i. Bitumen and bituminous mixture modified with SWPB and with WSCA withstood more loading, stretch less under loading and was less susceptible to temperature changes as compared to conventional binder. It is thus recommended that these materials be developed for use as bitumen and bituminous mixture modifier for road wearing course.

ii. The blending of SWPB and WSCA as a modifier yielded better mechanical properties for the binder than conventional binder. However, improvement was proportionately lower than when each of the modifier was used individually. It is thus recommended that the blend may not be used for modification.

5.2.2 Recommendations of Areas for Further Research.

i. The study limited its research on the modification of bitumen for the construction of the wearing course. It is recommended that further study to be carried out to determine the suitability of modifying bitumen with SWPB and WSCA for the other layers of the road.

ii. This study concentrated on modification of bitumen using waste particle size passing through sieve 2.36mm. Further research should be carried out to investigate the behavior of bitumen and bituminous mixture when modified with particle sizes greater than 2.36mm.

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Appendix 1: Sieve Analysis Results

University of Nairobi			ASPHALT MIX DESIGN			0/14 Wearing Course				
Department of Civil Engineering						Type 1				
HIGHWAYS LABORATORY										
Tested by:	Washinda/Ogalo			Standard:BS 598/812/Rode Note 19						
Sampled date:	05-02-12			Project:	Aristocrat Quarry in Mlolongo					
Location:	Site		Specification:		Standard spec. for Road and B.					
Type of material:										
AGGREGATES										
Sample no	Nominal Size	Description and Source			TRIAL MIX- MEDIUM BLEND					
					Total Wt.		%	Wt.		
2	14/6	Aggregates			1100		22	242		
3	10/6	Aggregates			1100		23	253		
4	0/6	Quarry dust			1100		55	605		
1	Filler	OPC			1100		0	0		
SIEVE ANALYSIS % PASSING										
Sample Number	1	Cement	0/6	6/10	10/14	THEO.	DESIGN MIX			
% in Mix 100	**0**	**0**	**55**	**23**	**22**	COMBINED	SPEC. AC 0/14mm TYPE 1		Actual Gradi	
Sieve Size (mm)						GRADING				
20	100	100	100	100	100	100	**100**		10	
14	100	100	100	100	84.6	97	**90**	**100**	9	
10	100	100	100	95.4	10.4	79	**70**	**90**	78.	
6.3	100	100.0	99.4	43.5	0.0	65	**55**	**75**	62.	
4	100	100.0	88.5	0.0	0.0	49	**45**	**63**	49.	
2	100	100.0	70.9	0.0	0.0	39	**33**	**48**	39.	
1	100	100.0	44.5	0.0	0.0	24	**23**	**38**	24.	
0.425	100.0	100.0	27.7	0.0	0.0	15	**14**	**25**	15.	
0.3	100.0	100.0	22.2	0.0	0.0	12	**12**	**22**	13.	
0.15	100.0	100.0	16.6	0.0	0.0	9	**8**	**16**	10.	
0.075	90.0	97.6	13.7	0.0	0.0	8	**5**	**10**	8.	

Sieve Analysis Table.

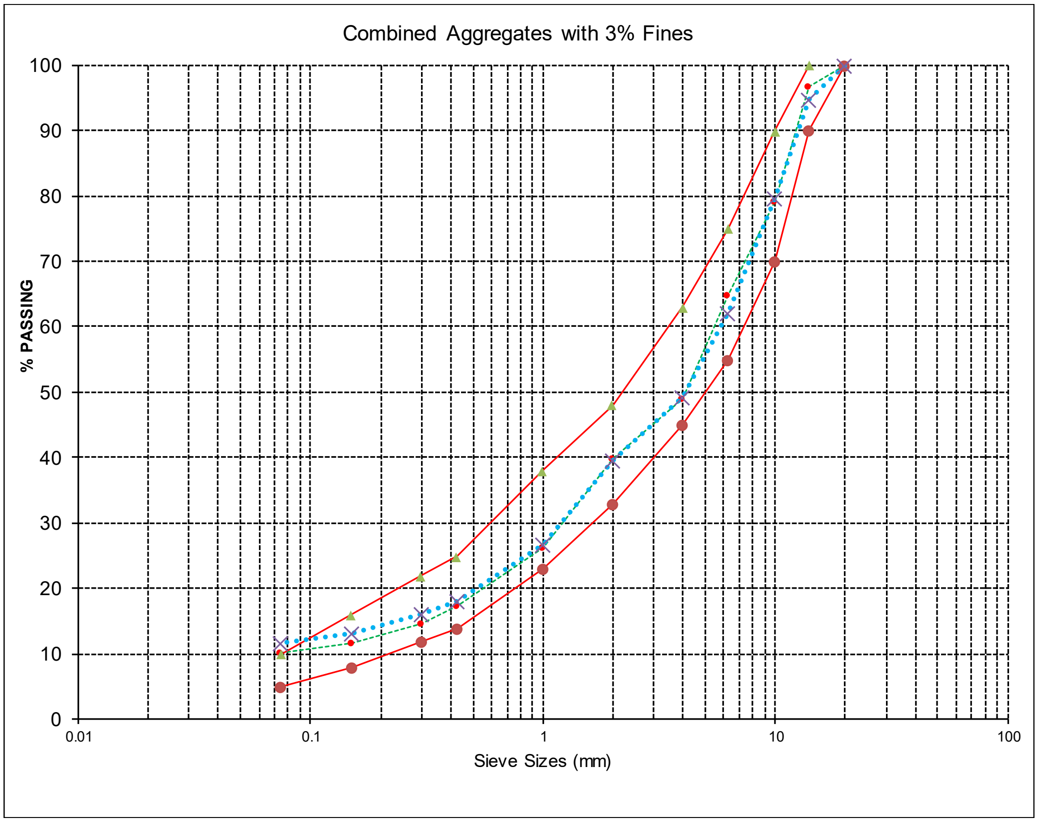
University of Nairobi		0/14 Wearing Course
Department of Civil Engineering	ASPHALT MIX DESIGN	Type 1
HIGHWAYS LABORATORY		

Tested by:	Washinda/Ogalo	Standard:BS 598/812/Rode Note 19	
Sampled date:	05-02-12	Project:	Aristocrat Quarry in Mlolongo
Location:	Site	Specification:	Standard spec. for Road and B.
Type of material:			

AGGREGATES			TRIAL MIX- MEDIUM BLEND		
Sample no	Nominal Size	Description and Source	Total Wt.	%	Wt.
2	14/6	Aggregates	1100	22	242
3	10/6	Aggregates	1100	23	253
4	0/6	Quarry dust	1100	52	572
1	Filler	OPC	1100	3	33

SIEVE ANALYSIS % PASSING									
Sample Number	1	Cement	0/6	10/6	14/6	THEO.	DESIGN MIX		
% in Mix 100	**0**	**3**	**52**	**23**	**22**	COMBINED	SPEC.		Actual Grading
Sieve Size (mm)						GRADING			
20	100	100	100	100	100	100	**100**		100
14	100	100	100	100	84.6	97	**90**	**100**	94.8
10	100	100	100	95.4	10.4	79	**70**	**90**	79.6
6.3	100	100.0	99.4	43.5	0.0	65	**55**	**75**	62.2
4	100	100.0	88.5	0.0	0.0	49	**45**	**63**	49.3
2	100	100.0	70.9	0.0	0.0	40	**33**	**48**	39.7
1	100	100.0	44.5	0.0	0.0	26	**23**	**38**	26.7
0.425	100.0	100.0	27.7	0.0	0.0	17	**14**	**25**	18
0.3	100.0	100.0	22.2	0.0	0.0	15	**12**	**22**	16.2
0.15	100.0	100.0	16.6	0.0	0.0	12	**8**	**16**	13.1
0.075	90.0	97.6	13.7	0.0	0.0	10	**5**	**10**	11.7

Sieve Analysis Table



Sieve curve Analysis

Appendix 2: Bitumen and Bituminous Results

TEST DESCRIPTION	TEST RESULTS BE MODIFICATION	SPECIFICATION:	
Penetration Grade 80/100	80/100	MIN	MAX
Penetration 25^0c (100g, 5s) 0.1mm	87	80	100
Penetration After Rolling Thin Film Oven Test (RTFOT) % of initial Penetration	56	50	
Softening point (Ring and Ball) ^{0c}(NEAT)	50	45	52
Softening Point After Rolling Thin Film Oven Test (RTFOT) ^{o}c	54	45	
Flash Point (Cleveland Open Cup) ^{0}c	250^{o}C	225	
Viscocity at 135^0c (Neat) cSt	224Cst		
Viscocity at 135^0c(After Rolling Thin Film Oven Test RTFOT) cSt		CHANGE	300%
Ductility at 25^oc, cm	100cm	100	
Ductility at 25^oc After Rolling Thin Film Oven Test (RTFOT), cm		75	
Specific gravity at 25^0c, g/cc	1.01	1.00	1.05
Thin Film Oven Test (TFOT) (5hrs at 163^0c) %			0.5
Loss on heating (5hr. 163^0c) % max.	0.2		0.5
Penetration on residue (100g-5s) % of initial Pen. Min.	87	80	

Conventional bitumen test results.

Conventional Bitumen							
Percentage Binder	Bulk Density Gb g/cc	Stability Value	Maximum Specific Gravity	Voids in Mix (VIM)	Voids in Mineral Aggregates	Voids Filled with Binder	Flow
4.5	2.16	10.78	2.35	7.78	17.40	55.31	2.41

5.0	2.18	11.72	2.32	5.93	16.70	64.50	2.60
5.5	2.16	12.03	2.26	4.33	16.10	73.10	2.96
6.0	2.15	11.28	2.23	3.63	16.40	77.84	3.37
6.5	2.14	10.22	2.20	2.93	16.70	82.47	3.68
Binder modified with 2% Shredded Waste Plastic Bags							
4.5	2.15	10.24	2.34	8.10	17.40	53.42	2.21
5.0	2.16	11.26	2.31	6.57	16.70	60.69	2.38
5.5	2.17	12.08	2.26	4.05	16.10	74.85	3.05
6.0	2.15	11.01	2.23	3.17	16.40	80.69	3.41
6.5	2.14	8.53	2.21	3.08	16.70	81.58	3.76
Binder modified with 3% shredded Waste Plastic Bags							
4.5	2.19	12.46	2.35	6.76	17.60	61.59	1.99
5.0	2.20	13.86	2.35	6.28	16.70	62.38	2.16
5.5	2.22	14.60	2.33	4.35	16.10	72.96	2.33

6.0	2.22	13.87	2.29	3.00	16.40	81.70	2.67
6.5	2.21	12.61	2.26	2.10	16.70	87.42	3.05
Binder modified with 2% Waste Sugar Cane Ash							
4.5	2.16	10.57	2.34	7.70	17.40	55.74	2.46
5.0	2.18	11.18	2.31	5.96	16.70	64.31	2.71
5.5	2.16	10.50	2.26	4.32	16.10	73.19	3.13
6.0	2.15	10.27	2.23	3.33	16.40	79.70	3.60
6.5	2.14	10.03	2.21	3.32	16.70	80.13	3.81
Binder modified with 2.5% Waste Sugar Cane Ash							
4.5	2.15	11.21	2.33	7.56	17.20	55.90	2.39
5.0	2.18	12.44	2.30	5.35	16.70	66.90	2.96
5.5	2.17	12.74	2.25	3.51	15.30	77.09	3.18
6.0	2.16	11.49	2.21	2.29	15.30	85.01	3.30
6.5	2.14	11.06	2.20	2.57	16.40	84.33	3.85

Binder modified with 1% SWPB and 2.0% Waste Sugar Cane Ash							
4.5	2.19	11.20	2.34	7.80	17.50	55.43	2.54
5.0	2.20	11.80	2.31	5.90	16.60	64.46	2.88
5.5	2.17	11.01	2.27	4.30	16.10	73.29	3.09
6.0	2.16	10.52	2.22	3.60	16.40	78.05	3.26
6.5	2.15	10.37	2.18	2.90	16.70	82.63	3.47
Binder modified with 2% SWPB and 1.5% Waste Sugar Cane Ash							
4.5	2.18	10.50	2.34	6.70	16.40	59.15	2.50
5.0	2.19	12.03	2.31	5.30	16.20	67.28	3.05
5.5	2.20	11.23	2.27	2.70	14.70	81.63	3.47
6.0	2.19	10.66	2.22	1.40	14.40	90.28	3.60
6.5	2.12	10.30	2.18	2.40	16.10	85.09	3.94

Data Sheets

Marshall Stability Test   Grade of Bitumen: Modified with 2 % SWPB and 1.5% SWCA

Type of grading aggregates: 0/6, 6/10, 10/   Compaction Temp. 160°C

Mixing temperature: 160 - 170°C   Data Sheet 7

Number of blows: 75

Date	Sample No.	% Binder	Height	Wt in Air (g)	Wt in Water (g)	Vol.	Bulk Density=Wt in Air/Vol.	Avg. Bulk Density	Stability	Stability (N)	Correction factor	Stability after correction	Avg Stability (KN)	Flow	Flow (mm	Avg Flow
	K		67	1132	612	520	2.177		258	10320	0.96	9907.2		200	2.54	
	L	4.50	67	1156	628	528	2.189	2.180	272	10880	0.96	10444.8	10.50	200	2.54	2.50
	M		67	1147	619	528	2.172		290	11600	0.96	11136		190	2.413	
	N		65	1134	618	516	2.198		320	12800	1	12800		250	3.175	
	O	5.00	66	1129	611	518	2.180	2.186	300	12000	1	12000	12.03	220	2.794	3.05
	P		66	1136	615	521	2.180		282	11280	1	11280		250	3.175	
	Q		66	1157	632	525	2.204		275	11000	0.96	10560		260	3.302	
	R	5.50	65	1147	631	516	2.223	2.204	290	11600	1	11600	11.23	290	3.683	3.47
	S		67	1158	628	530	2.185		300	12000	0.96	11520		270	3.429	
	T		68	1115	610	505	2.208		190	7600	1.04	7904		270	3.429	
	U	6.00	67	1171	635	536	2.185	2.187	353	14120	0.93	13131.6	10.66	270	3.429	3.60
	V		68	1140	614	526	2.167		285	11400	0.96	10944		310	3.937	
	W		68	1123	596	527	2.131		320	12800	0.96	12288		300	3.81	
	X	6.50	67	1126	596	530	2.125	2.124	235	9400	0.96	9024	10.30	280	3.556	3.94
	Y		67	1128	595	533	2.116		250	10000	0.96	9600		350	4.445	

Volume of the sample = Wt in Air - Wt in water

Density = Mass/volume

Correction factor

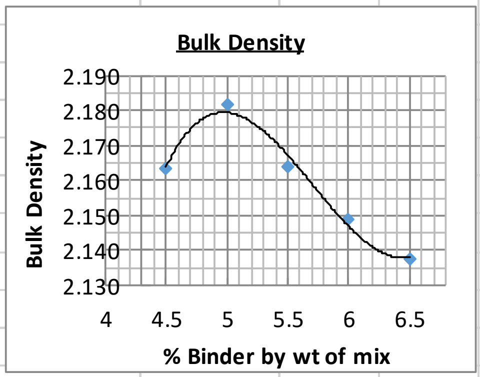
Stability = Multiply by 40N/Div

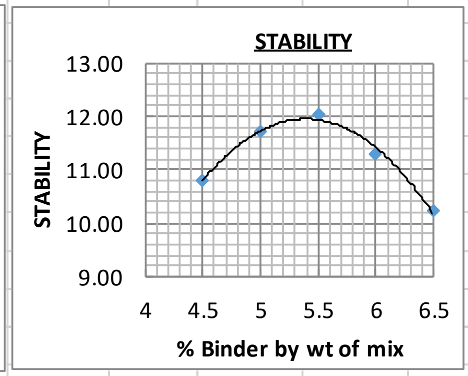
Flow = Multiply by 0.0127mm/Div.

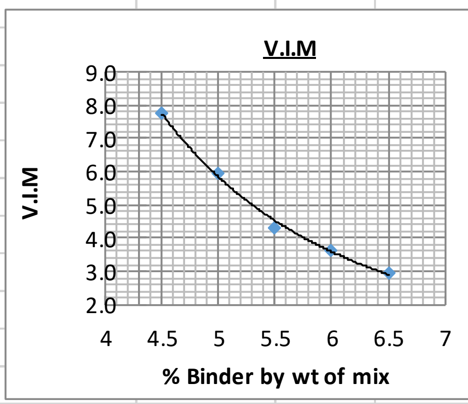
Results Marshall Stability Test Using Conventional Bitumen and Analysis

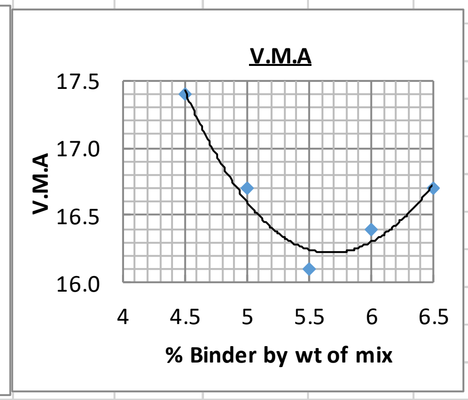
Marshall Stability Data for Conventioanl Bitumen					
PARAMETER	VALUES				
Binder content	4.5	5	5.5	6	6.5
Marshall Density	2.164	2.182	2.164	2.149	2.138
Marshall Stability	10.78	11.72	12.03	11.28	10.22
Maximum specific Gravity	2.346	2.319	2.262	2.23	2.202
Voids in Mix (VIM)	7.8	5.9	4.3	3.6	2.9
Voids In Mineral Aggregates	17.4	16.7	16.1	16.4	16.7
Voids Filled With Binder	55.3	64.5	73.1	77.8	82.5
Flow	2.41	2.60	2.96	3.37	3.68

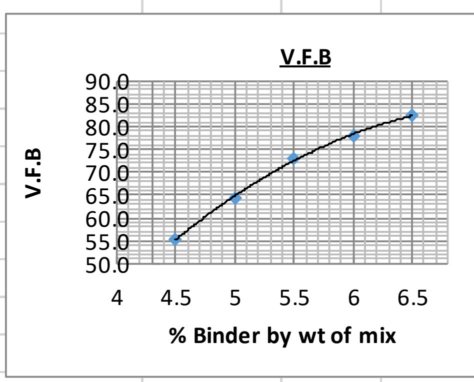
DESIGN CURVES

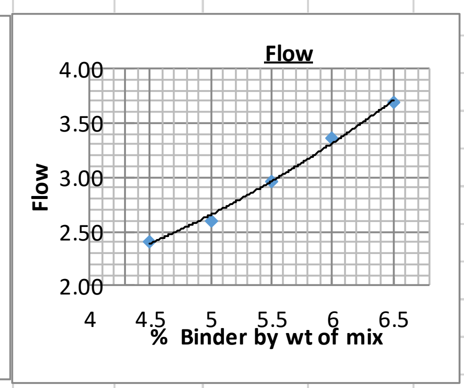












Marshall Stability Curves

DETERMINATION OF OPTIMUM BINDER CONTENT	
PARAMETER	BC
At maximum density - 2.18	5.00
At maximum Stability -11.9	5.50
At 4.6% Voids in Mix	5.50
At 16.25% Voids in Mineral Aggregates	5.70
At 70% Voids Filled With Binder	5.50
At 3mm Flow	5.50
TOTAL	32.70
Average	5.45

Therefore the optimum binder content is 5.5%

Optimum Binder Content for Briquette using Convention Bitumen

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet 2

Marshall Stability Test — Grade of Bitumen: Modified with 2% SWPB

Type of grading aggregates: 0/6, 6/10, 10/1 — Compaction Temp. 160°C

Mixing temperature: 160 - 170°C

Number of blows: 75

Date	Sample No.	% Binder	Height	Wt in Air	Wt in Water	Vol.	Bulk Density	Avg. Bulk density	Stability	Stability (N)	Correction factor	Stability after correction	Stability (kN)	Flow	Flow (mm)	Avg. Flow (mm)
	PA		63	1159	620	539	2.150		279	11160	0.93	10378.8		189	2.40	
22/5/2012	PB	4.5	63	1165	622	543	2.145	2.150	268	10720	0.96	10291.2	10.24	165	2.10	2.21
	PC		64	1166	625	541	2.155		270	10800	0.93	10044		168	2.13	
	PD		63	1151	620	531	2.168		280	11200	0.96	10752		189	2.40	
22/5/2012	PE	5.0	62	1135	610	525	2.162	2.162	310	12400	0.96	11904	11.26	190	2.41	2.38
	PF		63	1156	620	536	2.157		290	11600	0.96	11136		183	2.32	
	PG		63	1140	615	525	2.171		288	11520	1.00	11520		240	3.05	
23/5/2012	PH	5.5	63	1142	616	526	2.171	2.168	318	12720	1.00	12720	12.08	240	3.05	3.05
	PI		64	1155	621	534	2.163		300	12000	1.00	12000		240	3.05	
	PJ		63	1143	613	530	2.157		290	11600	0.96	11136		270	3.43	
23/5/2012	PK	6.0	63	1145	613	532	2.152	2.155	310	12400	0.96	11904	11.01	270	3.43	3.41
	PL		63	1142	612	530	2.155		260	10400	0.96	9984		265	3.37	
	PM		63	1164	612	552	2.109		211	8440	0.89	7511.6		298	3.78	
24/5/2012	PN	6.5	63	1143	615	528	2.165	2.142	215	8600	0.96	8256	8.53	302	3.84	3.76
	PO		63	1143	612	531	2.153		256	10240	0.96	9830.4		289	3.67	

Volume of the sample = Wt in Air - Wt in water

Density = Mass/volume

Conversion factors

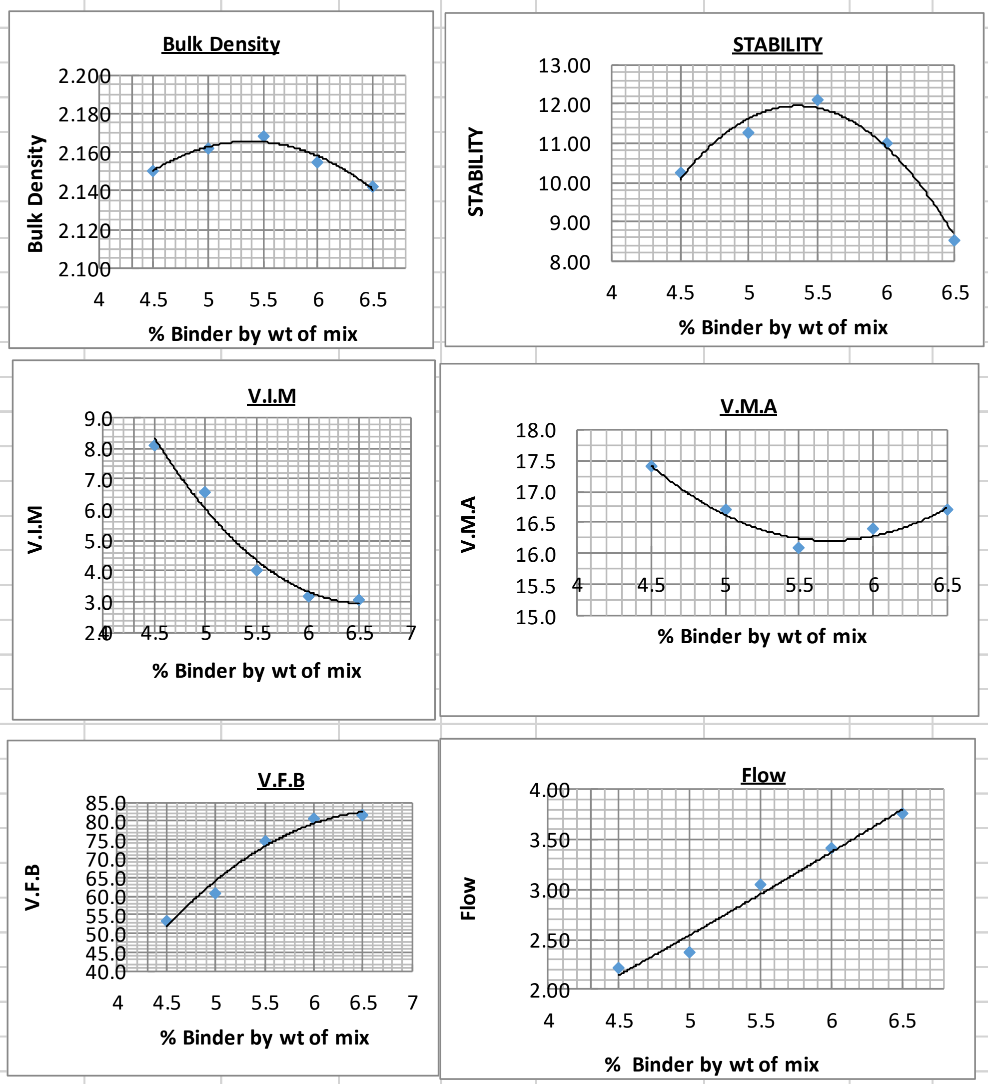
Stability = Multiply by 40N/Div

Flow = Multiply by 0.0127mm/Div.

Results of Marshall Stability Test Using 2% Shredded Waste Plastic Bags and the Analysis

MARSHALL DATA					
PARAMETER	VALUES				
Binder content	4.5	5	5.5	6	6.5
Marshall Density	2.150	2.162	2.168	2.155	2.142
Marshall Stability	10.24	11.26	12.08	11.01	8.53
Maximum specific Gravity	2.34	2.314	2.260	2.225	2.21
Voids in Mix (VIM)	8.1	6.6	4.0	3.2	3.1
Voids In Mineral Aggregates	17.4	16.7	16.1	16.4	16.7
Voids Filled With Binder	53.4	60.7	74.8	80.7	81.6
Flow	2.21	2.38	3.05	3.41	3.76

DESIGN CURVES



Marshall Stability Curves

DETERMINATION OF OPTIMUM BINDER CONTENT

PARAMETER			BC
At maximum density - 2.165			5.00
At maximum Stability -12.0			5.35
At 4.6% Voids in Mix (VIM)			5.40
At 16.2% Voids in Mineral Aggregates			5.70
At 74% Voids Filled With Binder			5.50
At 3mm Flow			5.55
		TOTAL	32.50
		Average	5.42

Therefore the optimum binder content is 5.4%

Optimum Binder Content for Briquette using 2% Shredded Waste Plastic Bags

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet 3

Marshall Stability Test — Grade of Bitumen: Modified with 3% SWPB

Type of grading aggregates: 0/6, 6/10, 10/1 — Compaction Temp. 160°C

Mixing temperature: 160 - 170°C

Number of blows: 75

Date	Sample No.	% Binder	Height	Wt in Air	Wt in Water	Vol.	Bulk Density	Avg. Bulk Density	Stability	Stability (N)	Correction factor	Stability after correction	Avg. Stability (kN)	Flow	Flow (mm)	Avg. flow
	A		67	1115	608	507	2.20		300	12000	1.04	12480		160	2.03	
22/5/2012	B	4.50	66	1111	606	505	2.20	2.191	320	12800	1.04	13312	12.46	150	1.91	1.99
	C		67	1111	600	511	2.17		290	11600	1.00	11600		160	2.03	
	D		67	1140	626	514	2.22		350	14000	1.00	14000		180	2.29	
22/5/2012	E	5.00	65	1116	611	505	2.21	2.201	340	13600	1.04	14144	13.86	160	2.03	2.16
	F		67	1147	620	527	2.18		350	14000	0.96	13440		170	2.16	
	G		68	1141	625	516	2.21		360	14400	1.00	14400		190	2.41	
23/5/2012	H	5.50	68	1136	620	516	2.20	2.224	350	14000	1.00	14000	14.60	180	2.29	2.33
	I		69	1118	623	495	2.26		370	14800	1.04	15392		180	2.29	
	J		67	1146	624	522	2.20		340	13600	1.00	13600		210	2.67	
23/5/2012	K	6.00	66	1147	630	517	2.22	2.216	350	14000	1.00	14000	13.87	210	2.67	2.67
	L		68	1140	630	510	2.24		350	14000	1.00	14000		210	2.67	
	M		66	1138	615	523	2.18		350	14000	0.96	13440		250	3.18	
24/5/2012	N	6.50	65	1128	620	508	2.22	2.213	320	12800	1.00	12800	12.61	230	2.92	3.05
	O		65	1143	633	510	2.24		290	11600	1.00	11600		240	3.05	

Volume of the sample = Wt in Air - Wt in water

Bulk Density = Weight in Air/volume

Conversion factors

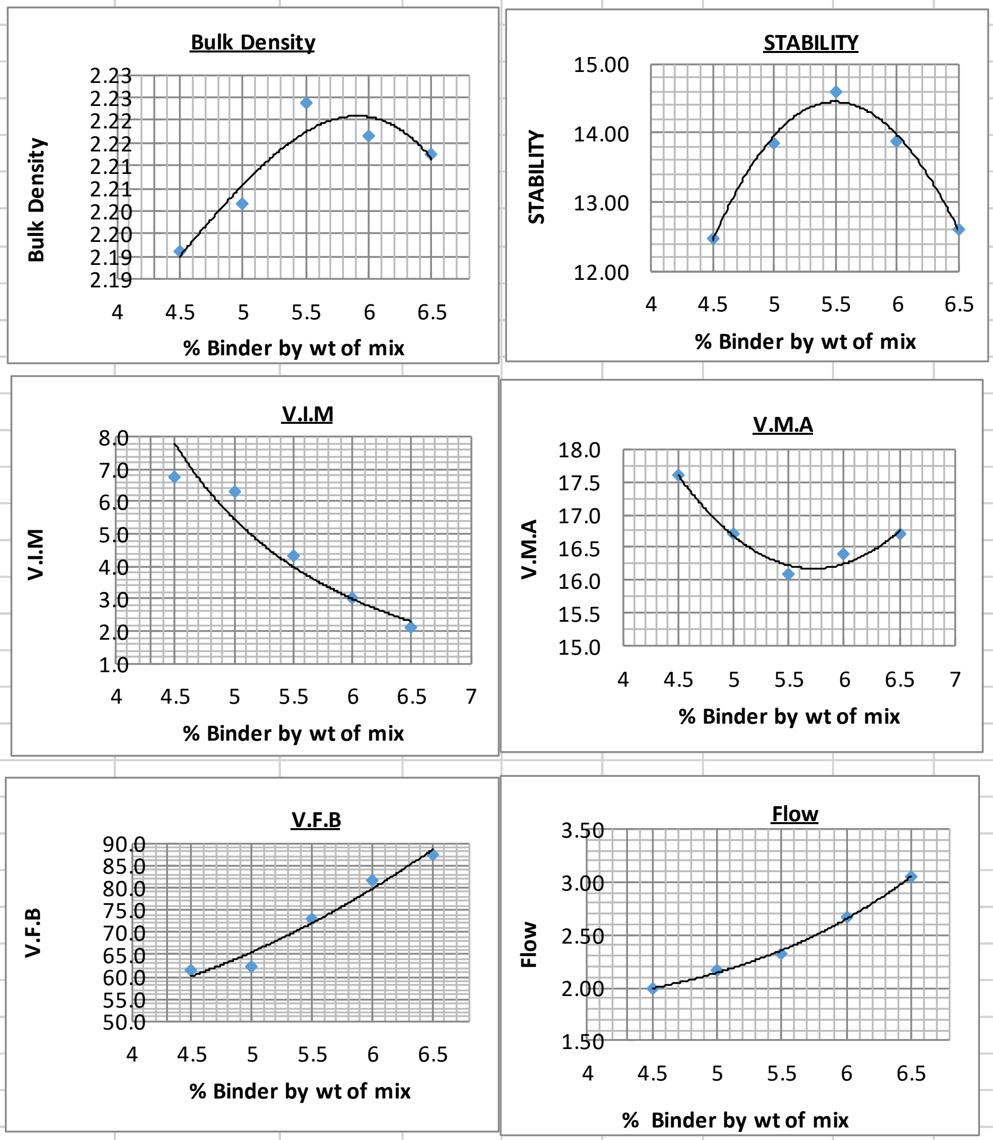
Stability = Multiply by 40N/Div

Flow = Multiply by 0.0127mm/Div.

Results Marshall Stability Test Using 3% Shredded Waste Plastic Bags

MARSHALL DATA					
PARAMETER	VALUES				
Binder content	4.5	5	5.5	6	6.5
Marshall Density	2.19	2.20	2.22	2.22	2.21
Marshall Stability	12.46	13.86	14.60	13.87	12.61
Maximum specific Gravity	2.350	2.349	2.325	2.285	2.260
Voids in Mix (VIM)	6.8	6.3	4.4	3.0	2.1
Voids In Mineral Aggregates	17.6	16.7	16.1	16.4	16.7
Voids Filled With Binder	61.6	62.4	73.0	81.7	87.4
Flow	1.99	2.16	2.33	2.67	3.05

DESIGN CURVES



Marshall Stability Curves using 3% Shredded Waste Plastic Bags

DETERMINATION OF OPTIMUM BINDER CONTENT

PARAMETER	BC
At maximum density - 2.22	5.90
At maximum Stability -14.4	5.50
At 4% Voids in Mix	5.50
At 16.2% Voids in Mineral Aggregates	5.75
At 73% Voids Filled With Binder	5.50
At 2.3mm Flow	5.50
TOTAL	33.65
Average	5.61

Therefore the optimum binder content is 5.6%

Optimum Binder Content for Briquette using 3% Shredded Waste Plastic Bags

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet 4

Marshall Stability Test | Grade of Bitumen: Modified with 2% SWCA

Type of grading aggregates: 0/6, 6/10 | Compaction Temp. 160°C

Mixing temperature: 160 - 170°C

Number of blows: 75

Date	Sample No.	% Binder	Height	Wt in Air	Wt in Water	Vol.	Bulk Density	Avg. Bulk Density	Stability	Stability (N)	Correction Factor	Stability after correction	Avg. Stability (kN)	Flow	Flow (mm)	Avg. Flow (mm)
	A		69	1147	615	532	2.16		250	10000	0.96	9600		190	2.41	
	B	4.50	69	1160	623	537	2.16	2.160	286	11440	0.96	10982.4	10.57	190	2.41	2.46
	C		66	1153	620	533	2.16		290	11600	0.96	11136		200	2.54	
	D		67	1148	618	530	2.17		260	10400	0.96	9984		210	2.67	
	E	5.00	67	1152	624	528	2.18	2.176	300	12000	0.93	11160	11.18	210	2.67	2.71
	F		67	1136	615	521	2.18		310	12400	1	12400		220	2.79	
	G		66	1145	614	531	2.16		290	11600	0.96	11136		250	3.18	
	H	5.50	66	1128	609	519	2.17	2.162	280	11200	0.93	10416	10.50	250	3.18	3.13
	I		67	1150	617	533	2.16		300	12000	0.83	9960		240	3.05	
	J		68	1170	620	550	2.13		270	10800	0.89	9612		320	4.06	
	K	6.00	67	1149	616	533	2.16	2.151	290	11600	0.93	10788	10.27	260	3.30	3.60
	L		67	1150	620	530	2.17		280	11200	0.93	10416		270	3.43	
	M		69	1150	620	530	2.17		250	10000	0.93	9300		300	3.81	
	N	6.50	68	1163	613	550	2.11	2.137	270	10800	0.96	10368	10.03	290	3.68	3.81
	O		68	1150	609	541	2.13		280	11200	0.93	10416		310	3.94	

Volume of the sample = Wt in Air - Wt in water

Density = Mass/volume

Conversion factor

Stability = Multiply by 40N/Div

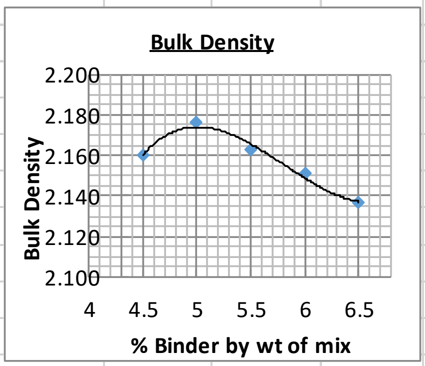
Flow = Multiply by 0.0127mm/Div.

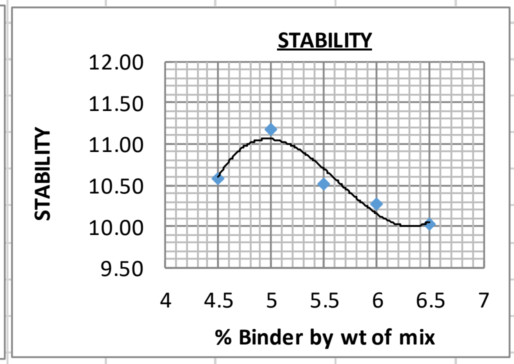
Marshall Stability Test Using 2% Waste Sugar Cane Ash

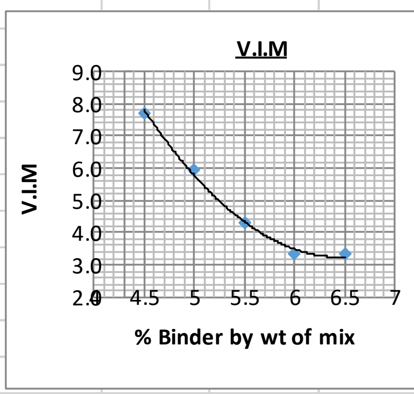
MARSHALL DATA

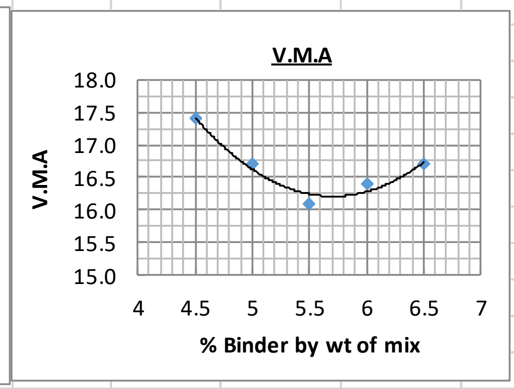
PARAMETER	VALUES				
Binder content	4.5	5	5.5	6	6.5
Marshall Density	2.160	2.176	2.162	2.151	2.137
Marshall Stability	10.57	11.18	10.50	10.27	10.03
Maximum specific Gravity	2.34	2.314	2.260	2.225	2.21
Voids in Mix (VIM)	7.7	6.0	4.3	3.3	3.3
Voids In Mineral Aggregates (VAM)	17.4	16.7	16.1	16.4	16.7
Voids Filled With Binder (VFB)	55.7	64.3	73.2	79.7	80.1
Flow	2.46	2.71	3.13	3.60	3.81

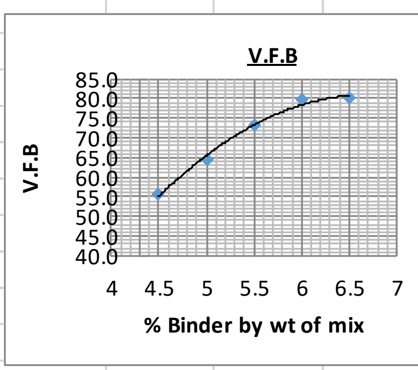
DESIGN CURVES

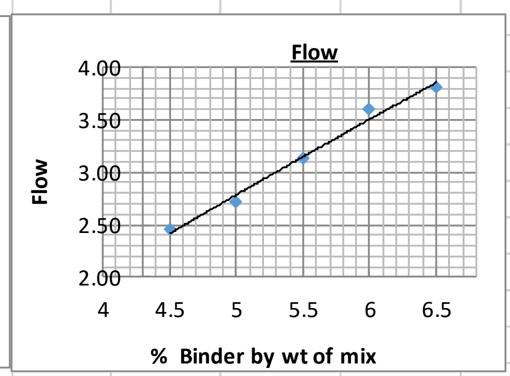












Marshall Stability Curves

DETERMINATION OF OPTIMUM BINDER CONTENT		
PARAMETER		BC
At maximum density - 2.173		5.00
At maximum Stability -11.1		5.00
At 4.6% Voids in Mix		5.55
At 16.2% Voids in Mineral Aggregates		5.70
At 74% Voids Filled With Binc		5.50
At 3.13mm Flow		5.50
	TOTAL	32.25
	Average	5.38
Therefore the optimum binder content is 5.4%		

Optimum Binder Content for Briquette using 2% Waste Sugar Cane Ash

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet 5

Marshall Stability Test — Grade of Bitumen: Modified with 2.5% SWCA

Type of grading aggregates: 0/6, 6/10, — Compaction Temp. 160^{o}C

Mixing temperature: 160 - 170^{o}C

Number of blows: 75

Date	Sample No.	% Binder	Height	Wt in Air	Wt in Water	Volume	Bulk Density	Avg. Bulk density	Stability	Stability (N)	Correction factor	Stability after correction	Avg. Stability (kN)	Flow	Flow (mm)	Avg. Flow (mm)
	M		66	1136	610	526	2.16		325	13000	0.96	12480		190	2.41	
	N	4.50	67	1150	615	535	2.15	2.15	283	11320	0.93	10527.6	11.21	180	2.29	2.39
	O		67	1130	605	525	2.15		277	11080	0.96	10636.8		195	2.48	
	P		65	1138	620	518	2.20		286	11440	1.00	11440		230	2.92	
	Q	5.00	67	1146	614	532	2.15	2.18	332	13280	0.96	12748.8	12.44	240	3.05	2.96
	R		66	1135	617	518	2.19		328	13120	1.00	13120		230	2.92	
	S		66	1119	600	519	2.16		313	12520	1.00	12520		260	3.30	
	T	5.50	66	1141	616	525	2.17	2.17	310	12400	0.96	11904	12.74	250	3.18	3.18
	U		66	1116	605	511	2.18		345	13800	1.00	13800		240	3.05	
	V		66	1154	610	544	2.12		284	11360	0.93	10564.8		260	3.30	
	W	6.00	65	1131	615	516	2.19	2.16	280	11200	1.00	11200	11.49	250	3.18	3.30
	X		66	1147	620	527	2.18		331	13240	0.96	12710.4		270	3.43	
	A1		67	1150	610	540	2.13		300	12000	0.93	11160		310	3.94	
	A2	6.50	66	1157	615	542	2.13	2.14	297	11880	0.93	11048.4	11.06	305	3.87	3.85
	A3		67	1161	625	536	2.17		295	11800	0.93	10974		295	3.75	

Volume of the sample = Wt in Air - Wt in water

Density = Mass/volume

Conversion factor

Stability = Multiply by 40N/Div

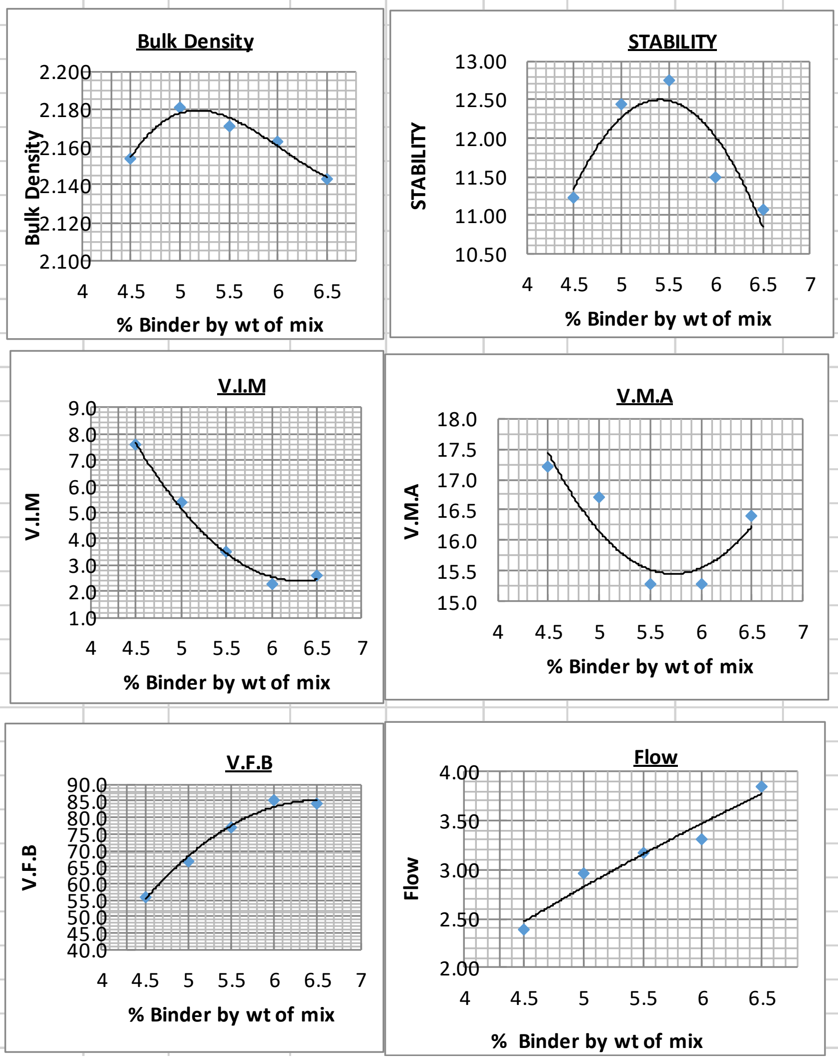
Flow = Multiply by 0.0127mm/Div.

Results of Marshall Stability Test Using 2.5% Waste Sugar Cane Ash and their Analysis

MARSHALL DATA

PARAMETER	VALUES				
Binder content	4.5	5	5.5	6	6.5
Marshall Density	2.154	2.181	2.171	2.163	2.143
Marshall Stability	11.21	12.44	12.74	11.49	11.06
Maximum specific Gravity	2.330	2.304	2.250	2.214	2.200
Voids in Mix (VIM)	7.6	5.4	3.5	2.3	2.6
Voids In Mineral Aggregates (VAM)	17.2	16.7	15.3	15.3	16.4
Voids Filled With Binder (VFB)	55.9	66.9	77.1	85.0	84.3
Flow	2.39	2.96	3.18	3.30	3.85

DESIGN CURVES



Marshall Stability Curves

DETERMINATION OF OPTIMUM BINDER CONTENT

PARAMETER	BC
At maximum density - 2.18	5.20
At maximum Stability -12.5	5.40
At 3.5% Voids in Mix	5.50
At 15.45% Voids in Mineral Aggregates	5.75
At 75% Voids Filled With Bir	5.30
At 3.2mm Flow	5.50
TOTAL	32.65
Average	5.44

Therefore the optimum binder content is 5.4%

Optimum Binder Content for Briquette using 2.5% Waste Sugar Cane Ash

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet 6

Marshall Stability Test   Grade of Bitumen: Modified with 1% SWPB and 2% SWCA

Type of grading aggregates: 0/6, 6/1(Compaction Temp. 160°C

Mixing temperature: 160 - 170°C

Number of blows: 75

Date	Sample No.	% Binder	Height	Wt in Air	Wt in Water	Volume	Bulk Density	Avg. Bulk Density	Stability	Stability (N)	Correction factor	Stability After correction	Avg. Stability (kN)	Flow	Flow (mm)	Avg. Flow (mm)
	P		66	1119	608	511	2.19		270	10800	1.00	10800		190	2.41	
	Q	4.50	66	1126	613	513	2.19	2.19	270	10800	1.00	10800	11.20	210	2.67	2.54
	R		66	1123	607	516	2.18		300	12000	1.00	12000		200	2.54	
	S		67	1134	621	513	2.21		316	12640	1.00	12640		200	2.54	
	T	5.00	67	1138	620	518	2.20	2.20	280	11200	1.00	11200	11.80	230	2.92	2.88
	U		67	1114	603	511	2.18		289	11560	1.00	11560		250	3.18	
	A		66	1138	622	516	2.21		295	11800	1.00	11800		250	3.18	
	B	5.50	67	1132	607	525	2.16	2.17	275	11000	0.96	10560	11.01	250	3.18	3.09
	C		66	1132	608	524	2.16		278	11120	0.96	10675.2		230	2.92	
	D		66	1143	614	529	2.16		284	11360	0.96	10905.6		250	3.18	
	E	6.00	68	1152	614	538	2.14	2.16	266	10640	0.93	9895.2	10.52	250	3.18	3.26
	F		65	1118	604	514	2.18		269	10760	1.00	10760		270	3.43	
	G		65	1134	607	527	2.15		294	11760	0.96	11289.6		260	3.30	
	H	6.50	67	1136	604	532	2.14	2.15	256	10240	0.96	9830.4	10.37	270	3.43	3.47
	I		67	1140	610	530	2.15		260	10400	0.96	9984		290	3.68	

Volume of the sample = Wt in Air - Wt in water

Density = Mass/volume

Conversion factor

Stability = Multiply by 40N/Div

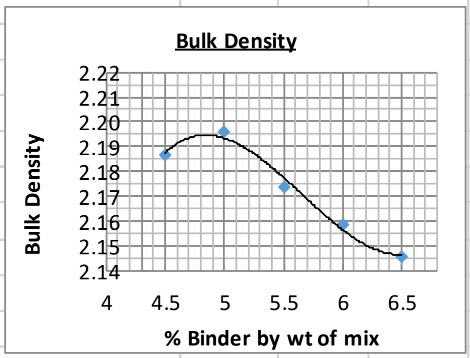
Flow = Multiply by 0.0127mm/Div.

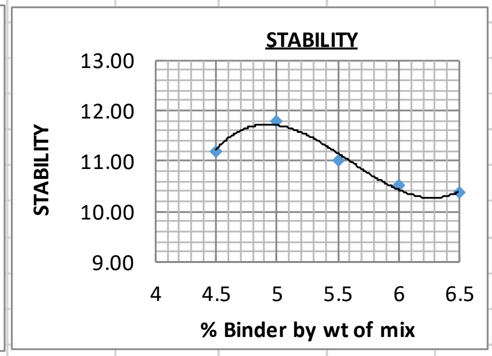
Marshall Stability Test Using 1% SWPB and 2% WSCA

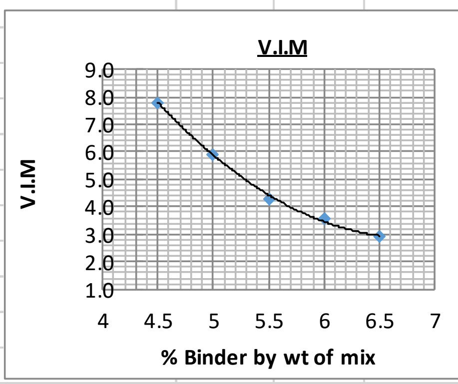
MARSHALL DATA

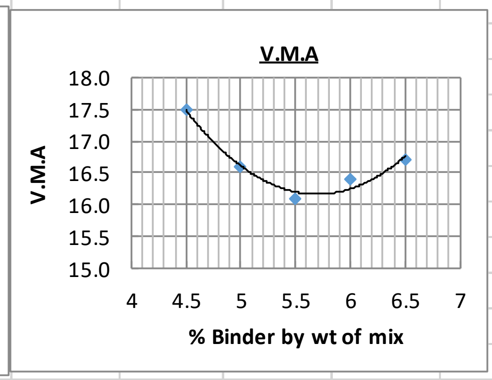
PARAMETER	VALUES				
Binder content	4.5	5	5.5	6	6.5
Marshall Density	2.19	2.20	2.17	2.16	2.15
Marshall Stability	11.20	11.80	11.01	10.52	10.37
Maximum specific Gravity	2.335	2.309	2.265	2.218	2.176
Voids in Mix (VIM)	7.8	5.9	4.3	3.6	2.9
Voids In Mineral Aggregates	17.5	16.6	16.1	16.4	16.7
Voids Filled With Binder	55.4	64.5	73.3	78.0	82.6
Flow	2.54	2.88	3.09	3.26	3.47

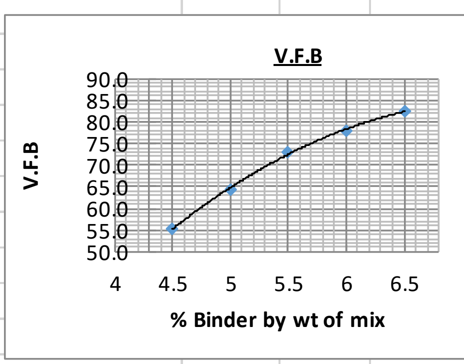
DESIGN CURVES

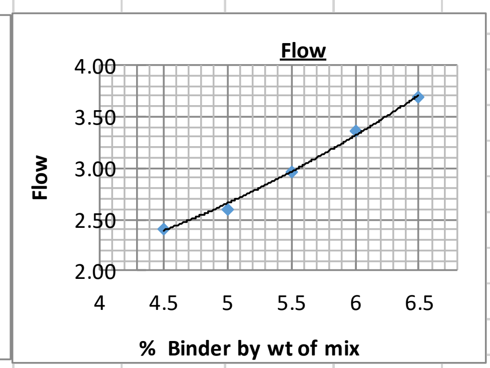












Marshall Stability Curves

DETERMINATION OF OPTIMUM BINDER CONTENT				
PARAMETER			BC	
At maximum density - 2.2			4.80	
At maximum Stability -11.65			5.00	
At 4% Voids in Mix			5.70	
At 16.2% Voids in Mineral Aggregates			5.70	
At 73.3% Voids Filled With Binder			5.50	
At 3mm Flow			5.55	
		TOTAL	32.25	
		Average	5.38	
Therefore the optimum binder content is 5.4%				

Optimum Binder Content for Briquette using 1% SWPB and 2% WSCA

Data Sheets

Marshall Stability Test — Grade of Bitumen: Modified with 2 % SWPB and 1.5% SWCA

Type of grading aggregates: 0/6, 6/10, 10/ — Compaction Temp. 160°C

Mixing temperature: 160 - 170°C — Data Sheet 7

Number of blows: 75

Date	Sample No.	% Binder	Height	Wt in Air (g)	Wt in Water (g)	Vol.	Bulk Density=Wt in Air/Vol.	Avg. Bulk Density	Stability	Stability (N)	Correction factor	Stability after correction	Avg Stability (KN)	Flow	Flow (mm	Avg Flow
	K		67	1132	612	520	2.177		258	10320	0.96	9907.2		200	2.54	
	L	4.50	67	1156	628	528	2.189	2.180	272	10880	0.96	10444.8	10.50	200	2.54	2.50
	M		67	1147	619	528	2.172		290	11600	0.96	11136		190	2.413	
	N		65	1134	618	516	2.198		320	12800	1	12800		250	3.175	
	O	5.00	66	1129	611	518	2.180	2.186	300	12000	1	12000	12.03	220	2.794	3.05
	P		66	1136	615	521	2.180		282	11280	1	11280		250	3.175	
	Q		66	1157	632	525	2.204		275	11000	0.96	10560		260	3.302	
	R	5.50	65	1147	631	516	2.223	2.204	290	11600	1	11600	11.23	290	3.683	3.47
	S		67	1158	628	530	2.185		300	12000	0.96	11520		270	3.429	
	T		68	1115	610	505	2.208		190	7600	1.04	7904		270	3.429	
	U	6.00	67	1171	635	536	2.185	2.187	353	14120	0.93	13131.6	10.66	270	3.429	3.60
	V		68	1140	614	526	2.167		285	11400	0.96	10944		310	3.937	
	W		68	1123	596	527	2.131		320	12800	0.96	12288		300	3.81	
	X	6.50	67	1126	596	530	2.125	2.124	235	9400	0.96	9024	10.30	280	3.556	3.94
	Y		67	1128	595	533	2.116		250	10000	0.96	9600		350	4.445	

Volume of the sample = Wt in Air - Wt in water

Density = Mass/volume

Correction factor

Stability = Multiply by 40N/Div

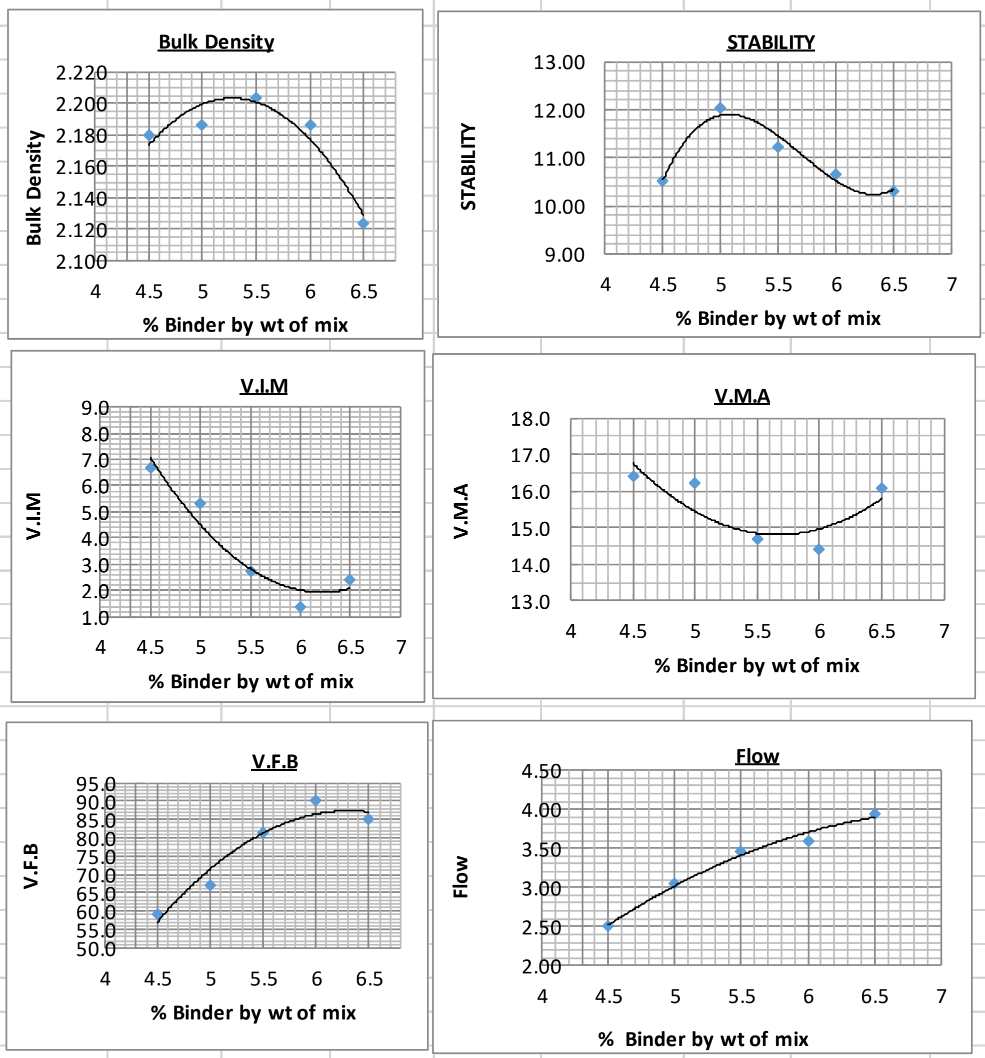
Flow = Multiply by 0.0127mm/Div.

Marshall Stability Test Using 2% SWPB and 1.5% WSCA

MARSHALL DATA

PARAMETER	VALUES				
Binder content	4.5	5	5.5	6	6.5
Marshall Density	2.180	2.186	2.204	2.187	2.124
Marshall Stability	10.50	12.03	11.23	10.66	10.30
Maximum specific Gravity	2.335	2.309	2.265	2.218	2.176
Voids in Mix (VIM)	6.7	5.3	2.7	1.4	2.4
Voids In Mineral Aggregates	16.4	16.2	14.7	14.4	16.1
Voids Filled With Binder	59.1	67.3	81.6	90.3	85.1
Flow	2.50	3.05	3.47	3.60	3.94

DESIGN CURVES



Marshall Stability Curves

DETERMINATION OF OPTIMUM BINDER CONTENT

PARAMETER	BC
At maximum density - 2.205	5.30
At maximum Stability -11.9	5.10
At 4% Voids in Mix	5.10
At 14.8% Voids in Mineral Aggregates	5.70
At 75% Voids Filled With Binder	5.20
At 3mm Flow	5.60
TOTAL	32.00
Average	5.33

Therefore the optimum binder content is 5.3%

Optimum Binder Content for Briquette using 2% SWPB and 1.5% WSCA

Appendix 3: Aggregates Results

Data Sheets					
MSC (Construction Engineering and Management)					
Marshall Test					
Data Sheet 1					
Aggregates Crushing Value					
Type of grading aggregates: 10/14					
Mixing temperature:					
Date	Sample No.	Total Weight	Total Weight Passing	Total Weight retained	ACV in %
	1	2752.10	566.20	2185.90	20.57
	2	2726.10	560.20	2165.90	20.55
	3	2765.50	574.60	2190.99	20.78
				Average ACV	20.63
ACV=Total Weight Passing/Total Weight x100					

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet 2

Aggregates Impact Value

Type of grading aggregates: 10/14

Mixing temperature:

Date	Sample No.	Total Weight	Total Weight Passing	Total Weight retained	AIV in %
	1	528.40	53.40	475.00	10.11
	2	546.00	55.30	490.70	10.13
	3	455.70	45.70	410.00	10.03
				Average ACV	10.09

AIV=Weight passing/Total Weight x 100

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet 3

Los Angeles Abrasion Test (LAA)

Type of grading aggregates: 10/14

Mixing temperature:

Date	Sample No.	Total Weight	Total Weight Passing	Total Weight retained	AIV in %
	1	5000.00	885.00	4115.00	17.70
	2	5000.00	886.00	4144.00	17.72
	3	5000.00	883.00	4117.00	17.66
				Average ACV	17.69

LAA=Weight passing/Total Weight x 100

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet 4

Soundness Test (SSS)

Type of grading aggregates: 10/14

Mixing temperature:

Date	Sample No.	Total Weight	Final Weight	Difference in Weight	SSS in %
	1	100.00	98.00	2.00	2.00
	2	105.00	103.00	2.00	1.90
	3	110.00	107.70	2.30	2.09
				Average SSS	2.00

SSS = Weight Lost/Initial weight x 100

Data Sheets

MSC (Construction Engineering and Management)

Marshall Test

Data Sheet5

Specific Gravity & Water Absorption

Type of grading aggregates: 10/14

Mixing temperature:

Date	Sample No.	Oven Dry Specimen (Wa)	Surface dried wgt (Wb)	Wgt in Water (Wc)	Wb-Wc	Wa-Wc	Wb-Wa	Gsb=Wb/(Wb-Wc)	Gsa =Wa/(Wa-Wc)	Abs=(B-A)/A
	1	1015.450	1022.450	652.150	370.300	363.300	7.000	2.761	2.795	0.689
	2	910.000	916.250	584.050	332.200	325.950	6.250	2.758	2.792	0.687
	3	1017.600	1024.700	651.950	372.750	365.650	7.100	2.749	2.783	0.698
	Average						6.783	2.756	2.790	0.691

Where

Wa is the weight of oven dried specimen in air

Wb is the weight in saturated surfaced dried specimen in air

Wc is weight of saturated surface dried specimen in air

Gsb is bulk specific gravity

Gse is effective specific gravity of aggregates

Gsa is apparent specific gravity of aggregates

Appendix 4: Stability Correction Ration

Table 1. Stability correlation ratio (from ASTM D1559)

Volume of specimen (cm^3)	Approximate thickness of specimen (mm)	Correlation ratio
200-213	25.4	5.56
214-225	27.0	5.00
226-237	28.6	4.55
238-250	30.2	4.17
251-264	31.8	3.85
265-276	33.3	3.57
277-289	34.9	3.33
290-301	36.5	3.03
302-316	38.1	2.78
317-328	39.7	2.50
329-340	41.3	2.27
341-353	42.9	2.08
354-367	44.4	1.92
368-379	46.0	1.79
380-392	47.6	1.67
393-405	49.2	1.56
406-420	50.8	1.47
421-431	52.4	1.39
432-443	54.0	1.32
444-456	55.6	1.25
457-470	57.2	1.19
471-482	58.7	1.14
483-495	60.3	1.09
496-508	61.9	1.04
509-522	**63.5**	**1.00**
523-535	65.1	0.96
536-546	66.7	0.93
547-559	68.3	0.89
560-573	69.8	0.86
574-585	71.4	0.83
586-598	73.0	0.81
599-610	74.6	0.78
611-625	76.2	0.76

Table 2. Marshall design criteria specified by LTA (PWD 1992)

Marshall stability (Number of blows =2 × 75)	≥ 9.00 kN
Flow value (in 0.254-mm unit)	8-16 units (2-4 mm)
Voids in total mix, VTM	3-5 %
Aggregate voids filled with bitumen binder, VFB	75-82 %