Thesis No…………

COLLEGE OF SCIENCE AND TECHNOLOGY

THE EFFECT OF SAWDUST ASH AND CEMENT STABILIZATION IN THE ASPHALT MIXTURE COMPOSED OF RECLAIMED ASPHALT PAVEMENT.

BY

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In partial fulfillment of the Requirement for the Degree of Master of Science in Civil Engineering, MSc. (Eng) (Highway Engineering and Management)

In the Faculty of Engineering, Department of Civil Engineering Environment and Geomatics Engineering University of Rwanda

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College of Science and Technology (Nyarugenge Campus, January 2021).

DECLARATION BY THE CANDIDATE

I, the undersigned hereby declare that the work presented in this thesis is my own work and has not previously in its entirety or in part been submitted for a Degree to any other University.

ABSTRACT

Recycling application in road maintenance and rehabilitation is of target concern for many developing countries as they focus on minimizing the cost due to budget constraint allocated to the sector of road infrastructure, as well as to give response to environmental concern in a way of reducing the disposal or land fill because pavement rehabilitation and reconstruction give big amount of quantities of Reclaimed Asphalt Pavement (Jie,2011). Moreover, in a world where more and more focus are being made on resources especially materials, the use of locally pavement materials such as sawdust ash and cement has been thought also to offer the suitable solution to the stabilization of RAP . The use of sawdust ash and cement for stabilizing the reclaimed asphalt has manifested a strong bond between them due to their similarity in terms of cementitious behavior to provide the performance to the mix for the surface course application.

This study provides different results and performance of the RAP materials associated with sawdust ash to improve for pavement through their effect within the mixture. The study will help in improving the performance of the pavement by utilizing the sawdust ash and cement in asphalt mixture, and evaluate the behavior of it through marshal test, a part from the pavement performance also this study will contribute to the environmental impact by minimizing the disposal of waste materials. This study evaluates the effect of sawdust ash as the filler replacement by 100%; 70%; 50%; 30% and 0% in the asphalt mix and reclaimed aggregate that showed the good performance in terms of flow and stability test conducted in laboratory as ordinary filler retained on sieve 75µm. The results obtained lied between the range of 8.5 as maximum at 5% bitumen and 3.5mm for the flow ,the results are in acceptable recommendation according to (TMH14,1985) .The processes that the research focus on, is the effect of sawdust and cement in the asphalt composed of aggregates and bitumen in terms of flow and stability for the mix.

Keywords*: Reclaimed Asphalt Pavement, sawdust ash, stabilization, stability, flow and filler.*

ACKNOWLEGDEMENT

I am giving credit to my thesis supervisor senior lecturer Dr. ABAHO Gershom for providing me with definite direction, professional guidance, constant encouragement from the beginning of the work and moral support in many ways during the thesis work.

I am also thankful to the University of Rwanda, College of Science and Technology for it valuable support through capacity building development for his scholarship in the campus.

I would like to thank also Mr. GWIZA Venerand highway laboratory technician for his support to carry out my experiment in the campus laboratory.

I would also give special thanks to my family who were in every day support and encouragement during my whole studies which were not easy due to the pandemic period of Covid-19.

I acknowledge the help, advice and guidance rendered by head of Civil Engineering and Geomatics Engineering Department in general, his support was of great importance.

I am also grateful to all the colleagues of the MSc. Highway Engineering and Management, their cooperation and support was incomparable and unforgettable!

I acknowledge also the last one but not least, my wife ‘’OLISA BEATHA ‘’for her endless encouragement all over the long studies journey, her support also was unforgettable!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL	DESCRIPTION
AASHTO	American association of state highway and transportation officials
AfCAP	Africa Community Access partnership
ADF	African development fund
AC	Asphalt cement
AIV	Aggregate impact value
^oC	Degree celcius
µm	micro
@	At
AAV	Aggregate abrasion value
ASTM	American society of testing material
BACMI	Britain roads at the start of 20th century
BS	British standard
BSM	Bitumen stabilized material
CBR	California bearing ration
Cm	Centimeter
CST	College of science and technology
CIPR	Cold in place recycling
CO2	Carbon dioxyde
DOTs	Department of transportation officials

EPA	Environmental Protection Agency
ESAL	Equivalent standard axle load
FDR	Full depth reclamation
FHWA	Federal Highways
HMA	Hot mix asphalt
IRI	International roughness index
KMH	Kanombe Military Hospital
LCA	Life cycle assessment
LCCA	Life cycle cost analysis
M_gO	Magnesium
OPC	Ordinary Portland cement
PCC	Portland cement concrete
PSI	Present serviceability index
RAS	Reclaimed asphalt shingles
RAP	Reclaimed asphalt pavement
SDA	Sawdust Ash
SA	South Africa
USA	United State of America

CHAPTER 1: INTRODUCTION

1.1. GENERAL

The reuse of pavement material such as reclaimed asphalt pavement (RAP) is a very crucial and powerful concept in today's application in road construction projects especially in rehabilitation and has been in practice since the 1930s (Chen et.al, 2014). The conventional road construction use the expensive materials such as virgin aggregates, bitumen, emulsion, foam processed from the industry to reduce the project expenses, the use of locally available material and reuse of materials were applied, many countries have been using RAP for highway construction .According to the Federal Highway Administration (FHWA),about 30 million tons of RAP are recycled into hot mix asphalt(HMA) pavements every year and thus RAP is the most recycled material worldwide(Oswald et.al,2011).

Also asphalt has been used as the construction material from the earliest days of civilization applied in ship construction as waterproofing material, its use in road project are recent (Roberts and Wang, 2002). The first roads were constructed for animals to be used for the farmers their features were only the markers to avoid marshes and other hospitable land and earlier the paved roads made of bricks and stones were reserved to the urban areas these roads seem to be started in middle east with binders a bonding material. An existing typical example is the processional road in Babylon that was constructed 620BC (Nicholls, 1992). The bituminous mixtures also rose to be utilized in road construction from dry stone developed by two pioneers Telfold and macadam. These inventors introduced individually dry bound mixture for pavements which were sprayed with a sealing tar blend to bind the aggregates together and provide a medium with a good water proofing properties but the traffic load caused by motor vehicle noticed the weaknesses in their performance (Hunter, 1994).

As the research went the researchers found the other asphalt mixtures which gave impermeable surfacing that would not produce dust and resist to permanent deformation. And the damage and deterioration of the roads become limited, though the road deterioration have started to be worsened the solution were the rehabilitation to maintain the roads at their original state many defects appear and require a huge amount of resources including money it is in that regard that

This study shows that the use of sawdust ash, bitumen and cement in the asphalt mixture is also a solution for pavement construction that can lead to the successful achievement of good performance of the surface layer toward sustainability of roads infrastructure (Gatot, 2011). Stabilization of RAP with bitumen associated with partially sawdust, cement has been thought to be successful to prove the usefulness of the reuse of pavement materials. (Papagiannakis,2008).

Regarding the situation of some road in the country rehabilitation by using the RAP stabilized is the effective method cost reduction and environmental friendly, considering the reuse of asphalt and aggregate and stabilizing with sawdust ash as new stabilizing material due to its pozollanic properties it has showed the presence of calcium oxide(CaO) the cimentitious indicator of 10% (Agarwal ,2004).This study is important for a road network of Rwanda to contribute to the sustainability and remedies to the rehabilitation cost effective.

The condition of a road should be assessed in order to know the extent of the failure for action. When pavement reaches its end of life it may remain in place and be reused as part of supporting structure for new pavement, recycled or removed and land filled. Each has economic and environmental cost, as do the more visible stages of the pavement life cycle (e.g. Material module, initial pavement construction and use phase.).Therefore and end of life activities can affect sustainability factors such as wastes generation and disposition air and water quality and materials use they must be considered in life cycle assessment(LCA) (Muluken, 2012).

1.2Research problem

Road networks in Rwanda play a major role in socio economic development of the country, and the infrastructure in the domain of transportation is keeping increasing what is to be proud of, the road sector strive to find a solution by identifying the optimal resources such as materials labor and money. This study is finding a solution by utilizing the reused materials stabilized with other locally available material such as sawdust ash to improve the performance of the mixture toward the pavement surface. Now road Networks in Rwanda consist of National road, District roads class I, district road class II, mainly unpaved and district feeder road. The roads once constructed the government strive to keep the roads in good condition to meet their life span, analysis period and design period depend on the class of road (Petri, 2019).

The total road network in Rwanda covers 37,898km, and this number includes paved, non-paved, classified and unclassified roads with road density 1.69km/km^2. (RTDA, 2019), report on road investment based on the type of road network and the total distance in kilometer, the density is one of the greatest in Africa. Table 1 below shows the details of road network classification in RWANDA.

Table 1: National Road Network

Classification	Length (km)
National road paved	1,390
National road unpaved	1,345
District road class1 paved	106
District road class1 unpaved	3,833
District road class2 paved	132
District road class2 unpaved	9,631
Unclassified road paved	345
Unclassified road unpaved	21,116
Total	37,898

The statistical road Network and their length are shown in the Figure 1 below

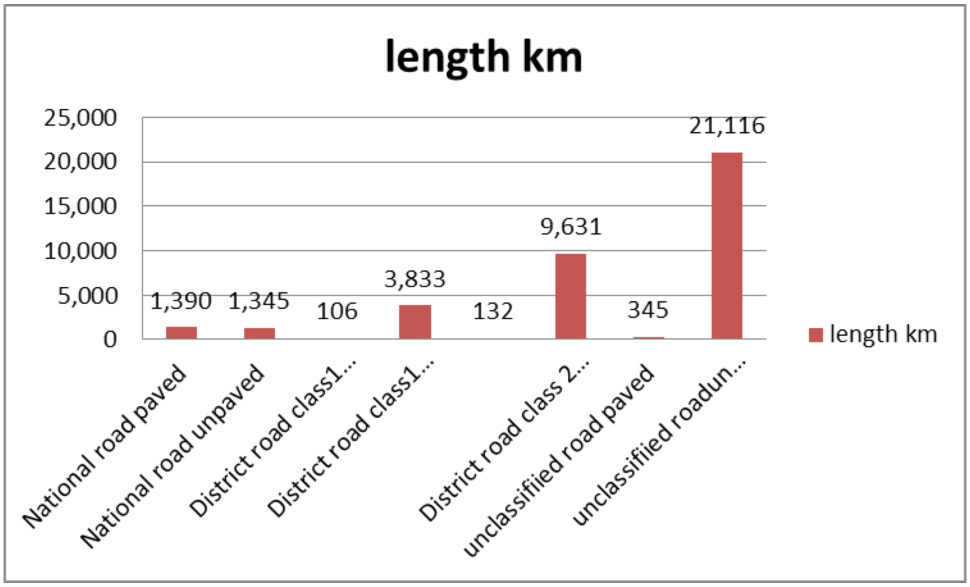


Figure 1: Road network of Rwanda

Also according to the roads investment condition the report of Mininfra in 2014 showed the condition of road measured IRI showed that the road in good condition as follows in figure 2

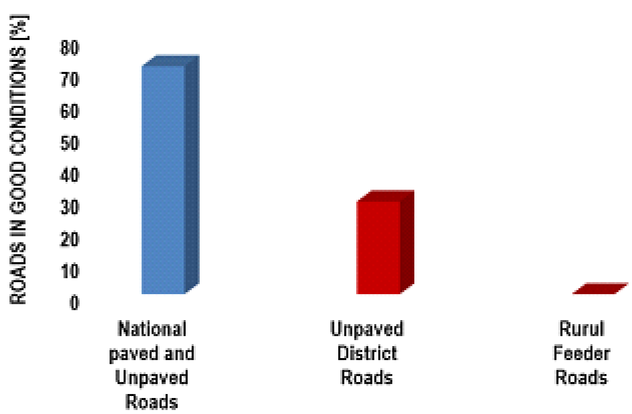


Figure 2: Road Condition

This shows the intervention that the government of Rwanda is dealing with, to preserve the road network by maintenance and rehabilitation, which however goes with the budget increase therefore to deal with budget constraint as well as environmental protection, the use of locally available material is a solution. The recycling of pavement material RAP has to be stabilized to attain the efficiency in terms of performance to the standards of road pavement and design. The recent method of maintenance and rehabilitation were the conventional where by a huge amount of money associated with time continued to be a problem (Emery, 1988).The use of

RAP to the asphaltic road will be the answer both economical safeguard as well as the environmental concern and performance of the surface layer in terms of comfort (IRI). The challenges accounted are the effect of sawdust ash and cement in the mixture.

All these challenges have fundamental objectives of responding to the pavement conditions issues especially for paved road networks in Rwanda that undergoes functional failure and structural failure as well such as fatigued materials that are potential sources of being reused. The research focuses on the use of RAP by application of cement and sawdust and bitumen stabilizers. Reclaimed asphalt is considered because it is obtained from milling and those materials are RAP aggregates (Khalaf, 2001).

1.3 Research objective

The aim of this work is to provide information on the effect of sawdust ash and cement as stabilizing materials in asphalt mixture replacing the mineral filler. It includes the involvement of reclaimed asphalt pavement stabilized with cement and sawdust ash to assess its behavior regarding the flow and stability.

My research is designed to achieve the following specific objectives:

1. To determine the physical and mechanical characteristics of reclaimed asphalt pavement(RAP)
2. To identify the chemicals and physical properties of sawdust ash and cement respectively
3. To extract the bitumen content in the RAP asphaltic
4. To analyze marshal stability and flow of the mixture RAP aggregates, sawdust ash and bitumen in different percentage.

1.4 Research scope

The effect of sawdust ash and cement stabilization of reclaimed asphalt is a study comprising socio economic and environmental analysis for the effect of recycled materials and all kind of the types of recycled material analysis of their physical characteristics, but this study is limited to the application of, cement and sawdust ash in the mixture to assess its behavior through marshal stability and flow of the mixture.

This study tends to provide the solution to the reduction of using virgin materials such as aggregates by opting to reuse them once aged, and use alternative manner of stabilizing them by using locally available material in reduction of cost and minimize the waste to zero.

1.4.1 Limitation of this study are as follows :

- The field sampling for the test were done only at one site KMH milled for recycling.
- Only RAP at 100 percent has been used and the percentage bitumen have been from 4 up to 6 percent.
- The mineral filler have been replaced by sawdust ash gradually in certain percentage from 30 to 100 percent.

1.5 outline of the Thesis

The Thesis is presented as follows:

Chapter 1 shows the background of the study, the research problem, research objective and scope respectively.

Chapter 2 shows the literature review on road conditions, mode of failure and different distress, type of maintenance. The chapter also talks about different recycled material that exists in road construction.

Chapter 3 Analyzes the methodology used to achieve the research objectives. The methodology consists, specifically, the methods of how to achieve the research objectives systematically.

Chapter 4 Deals with interpretation and presentation of results.

Chapter 5 Consists of in depth discussion of the results as they relate to the research question.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Paved road is about flexible pavement, constructed using asphalt as surface. The surface layers of the pavement carry and transmit traffic load to the subgrade. A flexible pavement is composed of four layers: Surface course, Base course, Sub-base course and subgrade (Sukirman, 1999). Surface course is the top of the pavement section; the layer is designed to have the highest stiffness as it carry the most important load from traffic i.e. heavy duty wheel all these load are spread to the underlying layer such as base, sub base and subgrade.

Base course is the layer located between the bottom layers and the surface layer which is called base course its function as foundation layers are to hold the latitude of the wheel loads and spread the load on the layer below, bearing of surface coating and layer front the bottom layer.

Subbase course is situated between the upper and the upper layers base layer of soil its function is to spread the wheel load to the ground floor ,it also prevent the ground water from collecting in the foundation .

Subgrade is the layer where other layers will be laid on the bottom of foundation are called the base ground layer. The base ground layer can be in the form of a compacted original soil if the original soil is good enough or the land imported from another place and compacted or stabilized soil with other materials like lime.

The top layer is on consideration for its great purpose of carrying the load and transmit to other layer and are susceptible of deterioration due to damage, the rehabilitation of the layer is to be studied by finding a solution of using stabilization and reclaimed asphalt pavement due to its cheaper and easy use the road are first of all monitored.

A thorough monitoring of the state of deterioration is necessary to permit an implementation of road construction projects including rehabilitation of existing road or up grading the gravel road to paved road, the action is demanding the use of materials such as reclaimed asphalt pavement and their stabilizers to enhance they strength (William et al., 1987).

Road condition is a major push of maintenance and rehabilitation action; in the world of finding the most economical solution the reuse of in place material has been a good alternative. Some roads are in such poor condition that normal maintenance is no longer sufficient or effective. In that case the roads now require rehabilitation using reprocessed pavement materials whose cost becomes less (Robinson, 1995).The performance of recycled asphalt pavement such as RAP by the application of sawdust ash and cement as stabilizer in the mixture are important (Carpenter, 2009). It is with reference to this and the objectives of this study, that this literature is structured.

The literature review consists of an overview of history of road construction and the development of road pavement (section 2.2), a review typical recycled materials (section 2.3) a review on cement and sawdust ash stabilizer (section 2.4), the review on the pavement deterioration (section 2.5) the following literature will deal with types of the functional feature (section 2.6) .Then (section 2.7) will deal with the literature on the characteristics of the sawdust ash and cement.

2.2 History of road construction and the Development of road pavement

Road pavements passed different stages in their developments since the start of the 20th century (David, 2005). The introduction of standards for pavement construction along with the introduction of mechanical means of producing and laying materials helped develop the modern road network (David, 2005). The increase traffic, rise in construction cost and environmental impacts have led to the introduction of performance specification and development of mixtures which reduce environmental impacts (EPA Ireland, 1998). This part describes some of the developments in road pavement construction over the last century.

2.3 Asphalt pavements

First used in Paris in 1854, they were made from natural rock asphalts (David and Byrine, 2005). The rock was limestone impregnated with binder (traditionally called bitumen) (David et al., 2005) .The material was imported into Britain and used in London in 1870 and persisted until 1930‘s The asphalt institute, (1984). It was very expensive material and was consequently utilized at prestigious sites only (Nicholls, 1997).

2.4 Concrete road

The first concrete roads were laid in Edinburgh 1865; it was a dry mix concrete with very little water in it and was compacted by steamroller, they proved to be unsuccessful, breaking up due to frost action, and were abandoned(Sherwood,1995). Improved materials and laying techniques saw their reintroduction in 1920, it was clear that the motor car was here to stay and something had to be done about the state of the road (Doncaster college,1999). The road board set up to increase the tax of fuel in order to raise funds for roads improvement 1909, the amount credited to the road improvement was raised up to $1.6millions per head of population

In 1919 the road board was absorbed into the newly created ministry of transport .there are followed a period of high activity and the road network was increasingly surfaced tarred mixtures of various forms until the Wall Street crash in 1929(BACMI1992).

2.5 Typical stabilizers

Different recycled materials were used for the road construction projects and have been assessed to be efficient (Smith et al., 2005). Some of the materials are more traditionally used in practice such as RAP and fly ash, while others are more unique to the specified reconstruction work those are:

2.5.1 Coal fly ash

Fly ash is a fine- grained, powdery produced from burning pulverized coal in a coal fired boiler at electrical generation plant (RMRC, 2010) .Fly ash for road construction applications is classified as either Class F or class C those two classes of fly ash are defined in ASTM C618: 1.Class F fly ash, and 2. Class C fly ash. Fly ash that is produced from the burning of anthracite or bituminous coal is typically pozzolanic and is referred to as a Class C fly ash if it meets the chemical composition and physical requirements specified in ASTM C618 that they contains less than 10 percent calcium lime (C_aO)or more than 10 percent lime(C_aO) content, and class F fly ash with pozzolanic properties ,glassy silica ,and alumina requires a cementing agent such as Portland cement ,quick lime or hydrated lime in the presence of water to react and produce cimentitious compound (Osinubi and Joseph, 2012). Thus class C fly ash will harden and get strength over tome in the presence of water (Osinubi and Joseph, 2012).

The two classes are pozzolanic, meaning that when finely divided and in the presence of water, the fly ash will combine with calcium hydroxide to form cementitious compound (ACCAA, 2003). However Class C fly ash has self cementitious cementing properties (i.e ability to harden and gain strength in the presence of water alone) that make Class C a more valuable and common fly ash in road pavement construction.

According to the American coal ash association (ACAA), Fly ash has been used in road and highway projects since the early 1950‘s (ACAA, 2003). Fly ash is often used for cement replacement in concrete and less commonly as fill stabilization in base material (Edil, 2013).In 2014 ,approximately 13.1 million tons of fly ash were used in concrete production (ACAA,2015).

Benefits of fly ash PCC unrelated to environment or economics include higher ultimate strength, improved workability, reduced bleeding reduced permeability and more. However disadvantages of fly ash substitution may include possible reduction in durability and reduced earl strength (ACCAA, 2003). In base courses, fly ash and lime can be combined with aggregate to improve the quality of the road layer. Although not as common a practice, studies have suggested many benefits of fly ash –improved base courses including increased strength and extended service life of the roadway (Wen et al., 2011).

2.5.2 Reclaimed Asphalt Pavement

2.5.2.1 Origin

Rclaimed asphalt pavement(RAP) is the term given to removed and or reprocessed pavement materials containing asphalt and aggregates. These matarials are generated when asphalts pavements are removed for reconstruction ,resurfacing ,or to obtain access to buried utilities (Osinubi and Joseph, 2012).. When properly crushed and screened ,RAP consist of high-quality ,well graded aggregate coated by asphalt cement (Gardner,2011).

Asphalt pavement is generally removed either by milling or full depth-removal by using the specified machine called milling machine which can remove up to 300mm thickness. Full depth removal involves ripping and breaking the pavement using a rhino horn on a buldozzer and or pneumatic pavement breakers . in most instances ,the broken material is picked up and loaded into haul tracks and front end loader and transported toa central facility for processing . At this

this facility ,the RAP is processed using a series of operation ,including clushing and screening (herman,2004).

2.5.2.2 Reclaimed Concrete Asphalt

RCA also known as reclaimed concrete material ,consist of high quality ,well graded aggregates bonded by hardened cementetious paste (Chesner et.,al 1998). RCA is generated from the demolition(Prestressed Cement Concrete (PCC) in not only roads ,but in other concrete structures. After demolition and excation ,the RCA is typically either hauled to a stockpiling facility (i.e aggregate suplier) landfilled ,or reused on site . At the stockpilling facility or at the site the RCA is crushed to the desired gradation and reinforcing steel is removed such that it can serve as a high quality base or subbase material (edil et al. ,2008). However the removal of some mesh reinforcement is difficullt consequantly decrease the quality of the RCA. The lower- quality RCA can be used as subgrade or fill material. the FHWA ,(2008) also discussed the effect of the presence of cementetious paste such as texture ,specific gravity and water absorption ,compared to the typical aggregate in the concrete.

here the form of stabilization according to Austroads are cement and cementetious blends where by cement products cover a wide range of property , the following explanation regard the cementetious products.

2.5.2.3 Portland Cement

Cement is the chief ingredient in cement paste ,the binding agent in Portland Cement Concrete (PCC) .it is an hydraulic cement that ,when combined with water ,harden into a solid mass .mixed with aggregate matrix it forms PCC. As a material portland cement has been used long time ago there is 175 years,and from an empilical perspective ,its behaviour is well understood. Chemically ,however ,portland cement is a complex substance whose mechanisms and interactions have yet to be fully defined .ASTM C 125 and the portland cement association (PCA) provide the following precise definition (Stiven, 2003).

1.hydraulic cement : an organic material or mixture of inorganic materials that sets and develops strength by chemical reaction with water by formation of hydrates and is capable of doing so under water.

1. Portland cement :hydraulic cement composed primarily of hydraulic calcium silicates .

2.6 Physical and Chemical properties

Portland cements can be characterised by their chemical composition. The basic chemical composition are shown in the Table 2 below according to (mindess and Young,1981).

Table 2: Chemical composition of Portland cement

Chemical name	Chemical formula	Shorthand notation	%by weight
Tricalcium cilicate	$3CaO \times SiO_2$	C_3S	50
Dicalcium cilicate	$2CaO \times SiO_2$	C_2S	25
Tricalcium aluminate	$3CaO \times Al2O_3$	C_3A	12
Tetracalcium Aluminoferrite	$4CaO \times Al_2O_3 \times Fe_2O_3$	C_4AF	8
Gypsum	$CaSO_4 \times H_2O$	CSH_2	3.5

2.6.1 Physical properties of cement

As definition cement is a binder, a substance used in construction industry with a huge value due to its properties of setting, hardens and adheres to other materials to bind them together. Cement is a seldom used on its own, but rather to bind sand and gravel or aggregate together. Cement mixed with fine aggregate produce mortar for masonry, or with sand and gravel produces concrete. Concrete is the largely used material in existence and is behind only water as the most useful in the world of construction of various infrastructures. (Williams, 2005).

Cement used in construction are characterized by their physical properties . Some important parameters control the quality of cement therefore the phsical properties of good cement are based on : fineness of cement ,soundness ,consistency ,strength ,setting time ,heat of hydration ,loss of ignition ,balk density and specific gravity . The Figure 5 below ullistrate the schematic properties of cement both phsical and chemical based on the paremeters cited previously.

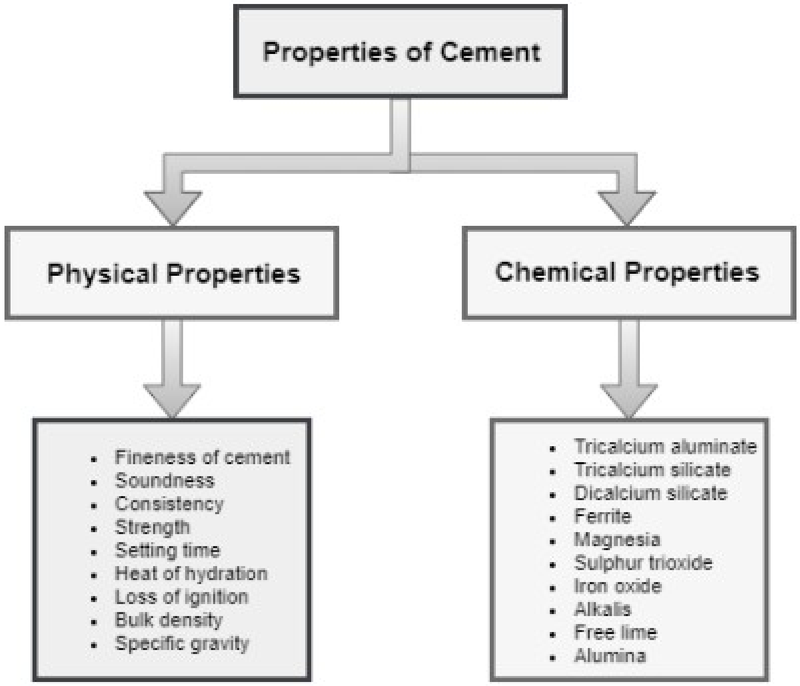


Figure 3: Physical and chemical properties of cement

- Fineness of cement

The size of the particles of the cement is its fineness. The required fineness of good cement is achieved through grinding the clinker in the last step of cement production process. As hydration rate of cement is directly related to the cement particle size, fineness of cement is very important.

- Soundness of cement

Soundness refers to the ability of cement to not shrink upon hardening. Good quality cement retains its volume after setting without delayed expansion, which is caused by excessive free lime and magnesia.

- Consistency of cement

Consistency of cement paste is its ability to flow .it is measured by Vicat Test . it is measured as follows : The plunger of the apparatus is brought down to touch the top surface of the cement. The plunger will penetrate the cement up to a certain depth depending on the consistency.

Cement is said to have a normal consistency when the plunger penetrates 10¡À1 mm.

- Strength of cement

Three types of strength of cement are measured compressive, tensile and flexural. Various factors affect the strength such as water-cement ratio, cement-fine aggregate ratio, curing conditions, size and shape of a specimen, the manner of molding and mixing, loading conditions and age.

Compressive Strength: It is the most common strength test. A test specimen (50mm) is taken and subjected to a compressive load until failure. The loading sequence must be within 20 seconds and 80 seconds.

Tensile strength: Though this test used to be common during the early years of cement production, now it does not offer any useful information about the properties of cement.

Flexural strength: This is actually a measure of tensile strength in bending. The test is performed in a 40 x40 x 160 mm cement mortar beam, which is loaded at its center point until failure.

- Setting time of cement

Cement sets and hardens when water is added. This setting time can vary depending on multiple factors, such as fineness of cement, cement-water ratio, chemical content, and admixtures. Cement used in construction should have an initial setting time that is not too low and a final setting time not too high. Hence, two setting times are measured:

Initial set: When the paste begins to stiffen noticeably (typically occurs within 30-45 minutes)

Final set: When the cement hardens, being able to sustain some load (occurs below 10 hours)

- Heat of hydration

When water is added to cement, the reaction that takes place is called hydration. Hydration generates heat, which can affect the quality of the cement and also be beneficial in maintaining curing temperature during cold weather.

On the other hand, when heat generation is high, especially in large structures, it may cause undesired stress.

The heat of hydration is affected most by C3S and C3A present in cement, and also by water-cement ratio, fineness and curing temperature.

The heat of hydration of Portland cement is calculated by determining the difference between the dry and the partially hydrated cement (obtained by comparing these at 7th and 28th days).

- Bulk density

When cement is mixed with water, the water replaces areas where there would normally be air. Because of that, the bulk density of cement is not very important. Cement has a varying range of density depending on the cement composition percentage. The density of cement may be anywhere from 62 to 78 pounds per cubic foot.

- Specific gravity

Specific gravity is generally used in mixture proportioning calculations. Portland cement has a specific gravity of 3.15, but other types of cement (for example, Portland-blast-furnace-slag and Portland-Pozzolan cement) may have specific gravities of about 2.90.

2.6. 2 Sawdust ash

Sawdust is a waste product of woodworking operations such as sawing ,milling ,planing and routing .it is composed of small chipping of wood. These operations can be performed by wood working machinery. The material are largery from woodwork industry or carpentry and then prcessed to become ash by burning them slowly in a container . The Figure 6 below shows the circula saw in a carpentry of GISOZI,and the sawdust to be collected and burned for finding the appropriate ash required for the research .

Figure 4: Sawdust burned to become sawdust ash (SDA).

Sawdust ash which was obtained was sieved and large particles retained on the 600micro meter sieve were discarded while those passing the sieve were used for the work this are particle size distribution shown in the figure 5 below.

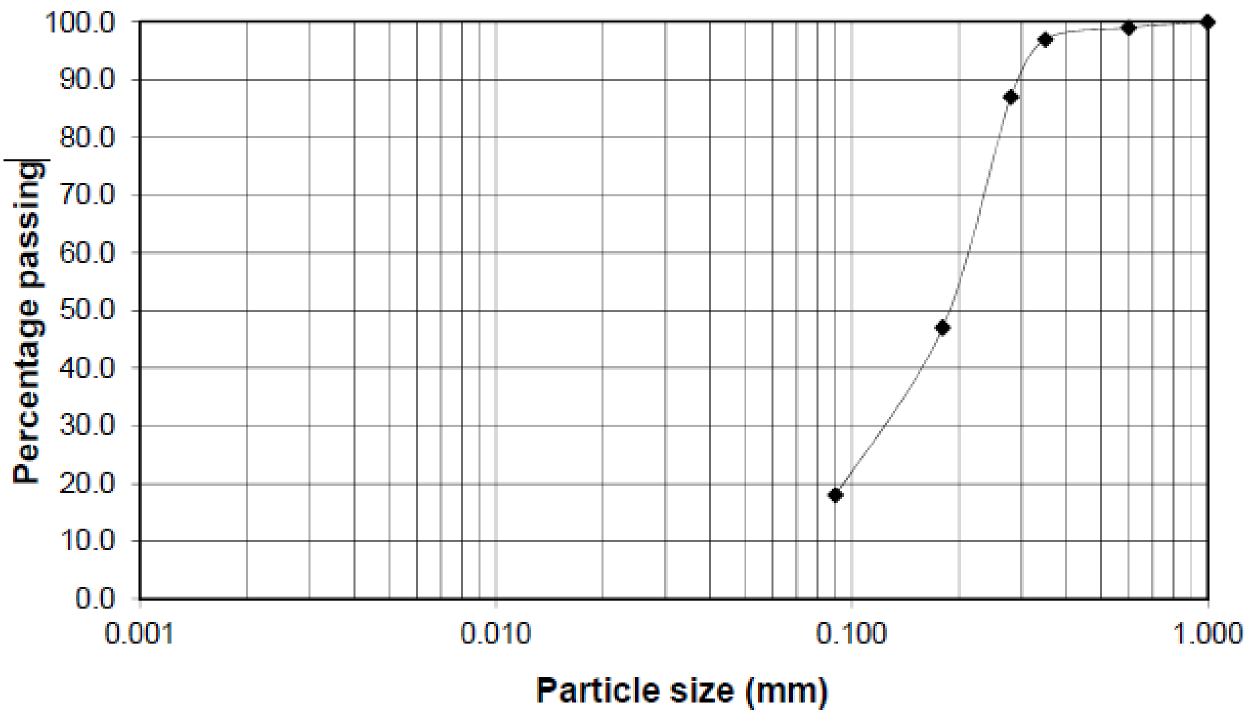


Figure 5: Particle size distribution

Chemical composition of sawdust ash

The chemical composition of sawdust ash proved to be the pozzolanic material and can be used as cement and or in partial replacement or blended cement. Chemical composition are shown in a Table 3 below :

Table 3: Chemical composition of Sawdust Ash (SDA)

Parameter	Alumina (Al_2O_3)	Silica (SiO_2)	Calcium (CaO)	iron (Fe_2O_3)	Magnesium (M_gO)	sodium (Na_2O)	potassium (K_2O)
%composition	9.85	62.87	10.35	4.45	4.18	0.035	1.17

Source :ASTM C 618 Standard

The composition of $SiO_2+Al_2O_3+Fe_2O_3$ is about 77.17% according to IS. 3812:2003 the SDA behave as Pozzolana material.

2.7 Pavement deterioration

Pavement deterioration is the process by which distress (defects) develop in the pavement under the combined effects of traffic loading and environmental conditions. (Norman , 2009).

2.7.1 Types of road defect

Road defect are different due to their causes, paved road may be structurally deteriorate or functionally deteriorates (Hoban et al., 1994). These two major types of deterioration are divided into sub types which are:

cracking is a load associated structural failure .the failure can be due to weakness in the surface ,base or subgrade knowing that the pavement structure of road in Rwanda is composed of three layers ,the illustrated pavement structure be a thin wearing course according to the Figure 6 illustrated below.

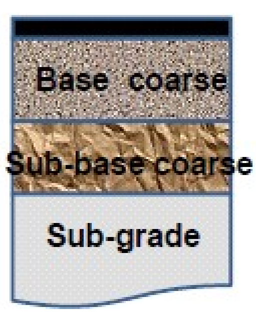


Figure 6: Pavement structure

Cracking may be longitudinal, transverse, block or crocodile therefore longitudinal cracking are cracks that are parallel to the pavements centerline or laydown deflection. (Brett , 2015).Whereas transverse cracking these type of cracks are not restricted to the wheel paths and may occur because of poor construction techniques (e.g. Asphalt overlay construction joint) settlement of embankments or active clay subgrades. These are line cracks running longitudinally along the pavement .they are often located near the edge of the pavement (Derek , 2011). Although these cracks are not normally caused by traffic, the action of traffic and lack of maintenance can lead to crocodile cracking in the wheel path in the form of small longitudinal cracks. The Figure 7 below illustrates the severe cracks on degree 5 according to (TMH9, 2008).The deterioration of that extent requires the full depth maintenance and the road must be undergoing the rehabilitation.

.

Figure 7: Severe crack degree five

Block cracking or stabilization crack therefore blocks are normally caused by the shrinkage of treated pavement layers, the cracks are not only confined to the wheel paths but also in the edge of the road ,there are characterized by cracks of definite block pattern and longitudinal and transverse cracks do not always meet. According to Derek P. (2011), the spacing of the cracks depends on the type of the material, the type and the quantity of stabilizing or modifying agent used; furthermore these kinds of defects cover a large area and may occur where there is no traffic.

The cracks do not necessarily indicate significant deterioration of the pavement but a potential for deterioration. Traffic action may lead to the formation of secondary cracks which could eventually lead to severe defects. It is often difficult to distinguish between block cracks and a combination of longitudinal and transverse cracks on a particular road segment. In such case cracks should be classified in one of two option i.e the more predominant type. The Figure 9 illustrates the stabilization crack/ block degree of deterioration 4 according to (TMH9 2008).

Then the Figure 9 which follows is showing another type of defect which is blocking cracking in severe condition that affects the serviceability, comfort due to the cracks. This kind of defect is predominant in developing countries where the structure of pavement condition is not considered much due to budget constraint allocated to the infrastructure such as roads and they opt for the alternative to the decision maker. Maintenance comes late though the increase of cost for road users, road agency .i.e operating cost, maintenance cost respectively. The Figure 8 below is showing the degree of deterioration rated 4.

Figure 8: Crack of degree 4 according to TMH9 (2008)

The following illustration is for defect called block crack in severe condition the Figure 9 as follows below.

Figure 10: Block crack in severe condition degree 5 according to the rating and extent of the distress (TMH9, 2008).

- Transverse cracks

Transverse crack are line cracks across the pavement. They are often a first manifestation of shrinkage in a cement stabilized base or sub-base ,but may also be a sign of active clay in the subgrade .Transverse cracks can also be a sign of a temperature associated fatigue and seasonal effect. They are normally not related to structural problems, but further deterioration of the pavement may occur with the ingress of water through the cracks. These cracks often occur at drainage structures or where services have been installed subsequent to initial construction by the pavement layers. They could indicate poor compaction of the material in the mediate vicinity of the cracks. Shrinkage cracks which often appear in an asphalt surface surfacing layer (map pattern) should not be noted as transverse cracks, but as surface cracks.

Crocodile or fatigue cracking is very often limited to the wheel path. Crocodile cracks normally occur as a result of fatigue of surfacing or base layers and are related to the inability of the pavement to carry the traffic load (Kallas, 1984). In addition, they may occur as a result traffic fatigue of dry or brittle surfacing layers in the wheel paths permitting the penetration of water into the pavement layers .in such cases there is initially no sign of rutting. Crocodile cracks also occur in isolated patches where failure is caused by poor drainage and sealed in moisture (Dong, 2017).

Initially crocodile cracking sometimes appears as fine irregular longitudinal cracks which grow progressively closer and eventually interconnect to form the familiar crocodile pattern (TMH9, 1998). These initially irregular fine cracks can be identified via visual assessment and rate the extent of the defect according to the indication of the pavement condition also TMH9 provide the way forward. Crocodile cracking also occurs as secondary cracking around primary line cracks. Higher degrees (degree >3) of crocodile crack are often accompanied by deformation. The Figure 11 below illustrates the crocodile cracking.

The Figure 11 below is showing the other defect accounted which is the crocodile cracks in severe condition.

Figure 11: Crocodile cracking degree 5

As conclusion paved road distress is the defect occur to the pavement structure caused by different factors such as traffic loading, climate, type of soil for subgrade, all these factors lead to the cracking resulting to the potholes finally poor riding quality. Traffic loading also affects the surface that results into deformation (smith et al.,1987).

2.7.2 Deformation

Deformation is the change in the road surface profile. This is manifested as an area of the pavement having its surface either above or below that of the original level. The following types of deformation are observed and may be assessed such as rutting and settlement or undulation.

Rutting results from compaction or shear deformation through the action of traffic and limited to the wheel paths. When the rutting is fairly wide and even shaped, the problem is normally in the lower pavement layers. When rutting is narrowed and more sharply defined, the problem normally lies within the upper pavement layers. Rutting frequently occurs together with crocodile cracking, especially for pavement structures with thin bituminous layers. (Hoban and Christopher,1987). The Figure 12 below shows the typical rutting example of degree five.

Figure 12: Rutting degree 5

2.7.3 Pumping

Pumping means the movement of the material constitutes the pavement underneath the slab or ejection of material from underneath the slab as a result of water pressure. The causes are the water accumulation underneath the slab. This can lead to linear cracking, corner breaks and faulting (Sparkes ,1945).

Pumping occurs when active pore pressures under traffic loading cause fine material to be pumped from within the pavement to the surface, normally through existing cracks (. Pumped out fines are visible along the cracks on the surfacing and there is usually a thin layer of fines next to the cracks which adheres to the surface layer. The figure13 below shows the degree of pumping distress failure according to (TMH9, 1992). Its degree of failure stand at severe state rated degree five. This is illustrated on the figure 13 below.

Figure13: Pumping distress degree 5

2.7.4 Potholing

Potholes mean loss of material from the base layer refer to structural failures and exclude surfacing failures (owing to loss of surfacing), the mechanism of failure is structured as the succession of traffic loading, leading to cracks and then fatigue of the surface material and finally pothole all the results of poor riding quality (AASHTO, 2009).The Figure 14 shows the pothole of severe state rated degree five. The surface is seriously deteriorated the result of bad riding quality, due to its severe state the intervention is needed in terms of rehabilitation.

The evaluation of this kind of defect is based on visual inspection as an important aspect to understanding the condition index of pavement, maintenance and rehabilitation needs and priorities at network level for pavement management system (PMS).The visual distress is described by recording: the type, degree and the extent of occurrence(TMH9,2009).

The condition index is the indication of the pavement distress and is showed within the spectrum of qualitative measure as Very Good, Good, Fair, Poor and Very poor rated from 1, 2, 3,4and 5 respectively. The figure14 below shows the pothole of degree 5.

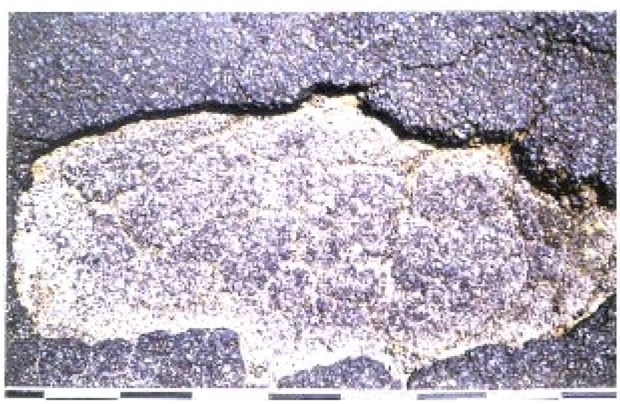


Figure 14: Potholes due to disintegration

Shows the failure occurred over a large areas and or secondary defects have developed owing to the failures (diameter >300mm) concentration of significant failures the indication of its rating of degree five.

2.8 FUNCTIONAL FEATURES

The functional requirements of a road reflect the service it provides to the road user .they are predominantly those that govern the comfort, safety and speed of travel refers to level of service, the level of service is said when there is an improved service for the resources available, i.e when the road capacity is improved and it is showing the best operating condition (Rajshahi,2019).

The various functional features to be regarded are the riding quality, skid resistance, surface drainage, and condition of the shoulders as well as edge breaking (Abulizi,2016).

2.8.1 Riding quality

The riding quality of a pavement is defined as the general extent to which road users are satisfied or not satisfied for the service on their behalf are rated .Riding quality is seen in terms of , smoothness and comfort of driver. This is the subjective evaluation of the pavement roughness (Chandra, 2002). Riding quality is described in the table 4 below.

Table 4: International Roughness Index

Degrees	Description	Approximate IRI*
(0)very good	Ride very smooth and very comfortable no unevenness of the road profile .no rutting raveling or even patching.	<2
(1)Good	Ride smooth, and comfortable slight an evenness of the road profile, slight rutting, raveling or uneven patching.	3
(2)fair	Ride fairly smooth and slightly uncomfortable intermittent moderate unevenness of the road profile, moderate rutting, raveling or uneven patching.	3.5
(3)poor	Ride poor and uncomfortable ,frequent moderate unevenness of the road profile frequent rutting raveling and uneven patching ,comfortable driving speed below speed limit .	4.5

(4)very poor	Ride very poor and very uncomfortable extensive severe unevenness of the road profile, extensive rutting, raveling uneven patching, and comfortable driving speed much lower than speed limit, road unsafe due to severe unevenness.	>6

Source World Bank,1986

IRI is average rectified slope (ratio of accumulated suspension motion to distance travelled at 80 km/h)

As it is said above, **0** =**perfect 4**=**Damaged**. **IRI** is calculated following the formula equ.1 below .**AASHTO PSI** is also a measure of riding quality (Present Service Index) was subjective rating between **0-5. 0** =very bad condition, 5= excellent performance, 2.5= maintenance required.

Performance criteria recommended for the assessment for riding quality is illustrated in the Table 5 below where also the present serviceability index is also showed.

Table 5: Standard riding quality

Road category	Riding quality			
	PSI		IRI	
	X	Y	X	Y
A	3.0	2.5	2.9	3.5
B	2.5	2.0	3.5	4.2
C	2.0	1.5	4.2	5.1

Riding quality is one of measure of functional requirements of a paved road, such as the measure of roughness or bumping as well as present serviceability index (PSI).

These parameters are measured or assessed to show the behavior of the paved skid resistance such as surface texture and friction. Some evaluation techniques of riding quality are based on AASHTO and IRI.

AASHTO, PSI is a measure basing on the axle load like considering single axles and tandem axles, the damage are different due to imposed traffic loads and type of vehicle. PSI was subjective to quality measures rating between 0 and 5. Whereby 0 =very bad condition, 5=excellent performance and 2.5=maintenance required (The Highway Capacity Manual, 2000).

International Roughness Index (IRI) is average rectified slope means ratio of accumulated suspension motion to distance travelled at 80 km/hr. and is rated from 0 to 5 where by 0=perfect ,5=damaged .However zero roughness is considered apparent practically, zero it is not used . The practical IRI lies between 2 and 3.5 for our road class B .The equation is $IRI = 7.436 - 4.132 \times \ln(PSI)$ Eq.1

2.9 RECYCLING TECHNOLOGY

2.9.1 INTRODUCTION TO PAVEMENT RECYCLING

Recycling is a reuse of pavement material when the materials have achieved their end of service (Khalaf , 2004). Recycling of existing pavement materials results in production of new materials used in pavement, preservation of money, time and energy are of great consideration, at the same time recycling of existing material also help in to solve the disposal problem (Byrne, 2002).

The preservation of existing transportation systems requires methods to rehabilitate and reconstruct roadways that reduce congestion during the construction process (Terrel,1978).There is also a need for more durable pavements that reduce costs for both transportation agencies and the traveling public(Little, 1978). In place recycling and reclamation of asphalt pavements lets highway agencies optimize the value of in place materials, minimize construction time and traffic flow disruption and reduce the number of construction vehicles moving into and out of the construction area (Epps, 1978).

In place recycling and reclamation is a method whereby an existing deteriorated asphalt pavement is renewed using in situ materials instead of virgin paving mixtures and materials, in place recycling and reclamation of asphalt pavement is rarely practiced in Rwanda, however some company started to use this technology recently they have proved that the technology is useful, and efficient (NPD, 2019).

Cold in place recycling (CIPR)

Cold in place recycling is a pavement rehabilitation technique that reuse the existing asphalt pavement(Swamy,1978) .This process is generally uses 100% reclaimed asphalt pavement (RAP) mixed by a new binder either emulsion ,foamed bitumen and cement as stabilizers. (Jenkins,2004) .Stabilization is the improvement of a soil or pavement material through the addition of a small amount of binder or additives. Some additives commonly used for stabilization (Hanks,1989).Granular and cementitious include Ordinally Portland Cement(PCC) and Cementitious Blend are used for stabilization in road construction especially base and sub-base (Meraka,2018).

This research is aimed on the use of saw dust ash as a partial replacement of Portland cement for stabilization of Reclaimed asphalt pavement in order to provide a compact mass especially for the asphalt mix used on the surface layer.

The asphalt recycling and reclaiming Association (ARRA, 2002) identifies five (3) broad categories of asphalt pavement recycling and reclaiming methods. These methods are: Hot recycling, cold planning or milling, Full depth reclamation (Magni , 1989).

1. Hot recycling involves mixing recycled asphalt pavement (RAP) with virgin aggregates and asphalt binder in a central mixing plant. A recycling agent may be added depending upon the mix design requirements. Hot recycling is the most widely used asphalt recycling method and while the asphalt pavement alliance estimates that nearly 100 million tons of RAP are produced each year worldwide 95% of the material is reused or recycled (David and Bryne, 2005).

2. Cold planning or milling is the removal of a predetermined depth of asphaltic concrete to a specific grade and cross slope (D.E.T.R, 1999) .Cold planning is unique in that action restores transverse and longitudinal profiles before placement of HMA surface course or a pavement preservation treatment, the milling action is accomplished using a cold planer with a rotary cutting drum (European Asphalt Pavement Association (EAPA), 1995).

Upon completion of the milling activity, a traversable surface remains that may treat with another recycling method or simply tacked and over lay with HMA course (Doncaster College, 1999).

Hot in place recycling consists of heating ,and thereby softening the existing asphalt pavement .the surface is then scarified with spring –loaded tines,augered or milled to specified depth .The cut debris of pavement are then mixed thoroughly ,placed and compacted. The equipment associated with the recycling process can stretch out over several hundred meter (Wrigten, 2000).

2.Full depth reclamation (FDR) is a technique where by the entire pavement structure or thickness, including the old pavement surfaces the bound base courses, any unbound granular bases and perhaps some of the subgrade, is pulverized or ground up into essentially a uniform particle size (David ,2006) . The pulverized material is blended and re-compacted to form a new uniform base for the new pavement surface. Various compounds can be used to bind this material together, such as heated asphalt binder, various asphalt emulsion, cement, fly ash, lime and water (Shuler, 2015).

Mechanical methods can also use for example the addition of granular material to change the gradation to obtain good compaction and density (Semelink , 2003).

Pavement conditions that is suitable for the full depth reclamation process includes:

Flexible pavement and unpaved roads, renewing the deteriorated roads by incorporating existing materials, that have been severely aged it means roads with high spots or depression due to underlying layers and or roads with many potholes and roads with plastic deformations such as Rutting, Shoving and Corrugations according to Hunter(1999).

Some advantages of full depth reclamation are to provide a good foundation structure and increase stiffness of the base materials (Asphalt Industry Alliance (AIA),2001). Other advantage is to reduce deflections from traffic, reduce subgrade stresses by preventing issues such as cracking and potholes.

Some agencies limit Full depth reclamation to low volume roads (1million ESAL s per design life) and to a total depth of 12 inch normally six to nine inches (Praveen, 2004). Many agencies require a minimum two inch overlay above the reclaimed base. Structural layer coefficients for Full depth reclamation layers generally range from 0.15 to 0.25 for full depth reclamation cement stabilized and 0.20 to 0.30 for FDR bituminous stabilized (David, 2006).

2.9.2 Materials for stabilization for RAP

2.9.2.1 Sawdust ash and ordinary Portland cement (OPC)

As we are striving to use locally available materials in road construction especially in rehabilitation, the use of sawdust ash and OPC as partial replacement is of more advantage because cement is widely noted to be most expensive constituent in the mixture example of Concrete (Ramzi et al., 2002).

According to ASTM,C618-1978) ,pozzolana is a siliceous or a siliceous aluminous material which contains little or cementitious value but in finely divided form and in the form and in the presence of moisture or water ,chemically reacts with calcium of moisture at ordinary temperature to form compound possessing cementitious properties . Such material includes sawdust ash due to the similar properties observed during experiment.

Saw dust is an organic waste resulting from the mechanical milling or processing of timber (wood) into various shapes and sizes. Saw dust ash has not found a known use or application as highway materials but have been used as partial replacement for cement in the making of bricks and concrete and had been found to contain pozzolanic properties in concrete (Sumaila, 1999). This statement is similar to be the significant observation when it is used in road rehabilitation as stabilizer replacing cement.

2.9.2.2 Reclaimed asphaltic concrete (RAC).

Reclaimed asphalt pavement is a term allocated to the removed or reprocessed pavement materials containing asphalt and aggregate and these are not to neglect because they are used again in the formation of a new road pavement (Mousa, 1999).

Asphalt concrete consists of a mixture of fine, course according to the grading specification to form a mixture of bituminous material such as emulsion or foamed. The RAP are generated when asphalts are removed for reconstruction, resurfacing or to obtain access to buried utilities. When crushed and screened reclaimed asphalts consist of high quality, well graded aggregate coated by asphalt cement according to FHWA user guidelines for byproduct and secondary use Materials in pavement construction (Harold,1951).

International experience and historic back ground

In developed country like United State of America (USA), where the concept of asphalt recycling had been in vogue, it is estimated that the amount of excess asphalt concrete that must be disposed is less than 20% of the annual amount of RAP (Garg, 1996). That is generated, but in developing countries like Nigeria, RAP is sometimes disposed in landfills or in the right of way, mixed with other materials as waste halting environment (Mousa, 1999).

Recycled RAP is almost always returned back into the roadway structure in some form ,usually incorporated into asphalt paving by means of hot or cold recycling and sometimes used as an aggregate in base or sub-base construction(Lundy et al.,1994).Although not always in the same year that is produced. The use of RAP in mixed asphalt is generally an accepted process, with an overall positive impact on the environment, (Ahmed, 1991). The percentage of RAP in hot mix normally varies from 10 -50% according to engineering technical letter ETL 1110 -3-503, 1999. RAP acceptance in road bases and sub-bases has been limited, because of lack of laboratory and field data. However, the use stabilized RAP as sub-base and base materials of pavement leads not only to economic solution. (Anouksak and Derek ,2006) ,but also offers a potential use of the RAP treated with a cemented materials like sawdust ash thus reducing the amount of waste materials requiring disposal and providing road construction materials with significant savings over new materials, (Schroeder, 1994).

The engineering properties of Reclaimed asphalt concrete are extremely dependent on the properties of the constituent materials and asphalts concrete type used in the old pavement (Garg and Thomson, 1996).

The quality control needed to ensure that the processed RAP is good for the application, depend upon how RAP has been obtained such as sources of old pavement, hence the quality can vary. This is the case for in place recycling the research has established the range of particle size distribution, physical, chemical, engineering and mechanical properties of RAP (Krlsson, and Isaacsson ,2006).

Fly ash is a pozzalana , which when combined with calcium oxide and water forms cementitious materials(Sasi ,et. al,2017) .Fly ash can be classified as either class F that contains less than 10% lime (CaO) or class C with more than 10% lime (CaO) content . Class F fly ash (with pozzolanic properties ,glassy silica and alumina) requires a cementing agent such as Portland ,quick lime or hydrated lime in the presence of water to react and produce cementitious compounds(Raheem,2012).

On the other hand class C fly ash will harden and gain strength overtime with the presence of water. While those classes are considered to be pozzolanic, class C fly ash is usually self-hardening (Halstead,1986). Fly ash is one of the few waste materials that has an American society of testing and materials ASTM C618-92a, 1994 standard for procedures of sampling and testing. Depending on the use and requirements fly ash can be used to replace some of the cement in admixture treatment of a deficient material.

Historically, about one third of the wood harvest in a year by the logging and lumbering the factories end up as a waste material .this waste takes the form of logging residues woods and bark chips from planning action ,and sawdust from sawing action. Wood ash is a solid residue of the combustion of sawdust or wood in air and is composed of carbonates and oxides of metals (e.g. Calcium and potassium) originally compounded in the plant woody tissues that are present in the residue (Babayemi and Adewuyi ,2010).

Most woods contain about 0.05 to 2.0 weight % of noncombustible materials, which is predominantly potassium oxide (KO_2) (Ismail, 2011). When waste wood particles such as sawdust are burned the noncombustible materials remain as a wood fly ash which normally is carried with the combustion products through the flue gas stack into the atmosphere. Because the properties of RAP are largely dependent on the properties of the constituent materials and asphalt concrete type used in the old pavement, the quality of RAP obtained from any number of old pavement sources can vary. Excess granular material or soils or even debris, can sometimes be introduced into old pavement stockpiles. The number of times has been resurfaced; the amount of patching or crack sealing and the possible presence of prior seal coat applications will all have the influence on the RAP composition. The major elements in sawdust ash are Calcium, Potassium and Magnesium, while Sulfur, Phosphorus, and Manganese are present at about 1% and Iron Aluminum, Copper, Zinc, Sodium, Silicon and Boron are present in relatively smaller amount (Misra et al., 2010).

CHAPTER 3: MATERIALS AND METHODS

3.1: MATERIALS

The reclaimed asphalt pavement (RAP) used in this research was obtained from KANOMBE MILITARY HOSPITAL (KMH) low volume road rehabilitation executed by NPD-COTRACO on his project of in place recycling application. The RAP consists of high -quality, well graded aggregate coated with asphalt cement (Krlsson, and Isaacsson ,2006). The RAP were processed in and extracted from bitumen and the aggregate were used for the study. First sieved and used for asphalt mix. And other materials like bitumen was found at university of Rwanda CST laboratory of the characteristics are as follows as it is seen on the below Table 6.

Table 6: Materials characteristics

Bitumen properties		Penetration at 25^{0}c dmm
		79
Penetration index		-0.5
	Temperature	30

Normally reclaimed asphalt pavement (RAP) is the term given to removed and or/reprocessed pavement materials containing asphalt and aggregates. These materials are usually generated from milling, pavement removal and waste taken from existing paved road (Kallas, 1994).

The RAP used was brought in University of Rwanda, College of science and technology laboratory especially highway laboratory to be tested: first the test of bitumen extraction was performed .This test consists of separating the aged bitumen from aggregate, and remains with the mixture of coarse aggregate , fine aggregate and sand dust.

Grading analysis was performed then to make the mixture, smaller sample size for grading analysis in accordance to ASTM C 702. The RAP was air dried before use for the test. Then the other physical and mechanical properties were analyzed through laboratory test such as Aggregate Impact Value Test, Los Angeles Abrasion value Test, Flakiness Index Test and Elongation Index Test.

Saw dust – sawdust was obtained from the carpentry Workshop University of Rwanda –college of science and technology then burned to convert into ash to be utilized in this research. The ash was passed through a sieve No .200 with 0.075 mm aperture before use for the study. The figure 15 below illustrates the sample obtained after burning the sawdust to become SDA.

Figure 15: Sawdust ash sample and crushed stone dust

Saw dust ash is a good partial replacement of cement in stabilization as it shows to contain pozzolanic properties in concrete, the reason to be used in recycled asphalt concrete for highway rehabilitation and maintenance (Praveen, 2015). Cement and sawdust ash were used as mineral filler to perform the marshal test to analyze the performance of the mixture flow and stability. The 79 penetration grade bitumen was chosen for the research.

3.2 Methodology

This research evaluates the performance of RAP stabilized with the sawdust ash and cement as partially replacement of active filler in the mixture (AC). This was achieved by preparing the samples including RAP aggregates by bitumen extraction a three samples A, B and C the extraction was done by centrifuge method by using the dichlomethane liquid reactant in form of solution poured in the reclaimed asphalt pavement (RAP), the aggregates of 552 grams were first extracted and ready to be sieved for gradation from 12.5 up 0.075mm.the bitumen properties were also determined as seen in table 6 in order to know the stiffness of the binder later in the analysis of the penetration , softening points as they are important.

Separate the bitumen from aggregates and preparation of bitumen and heat it at 190^{O}c and at different percentage 4; 5; 5.5 and 6 thoroughly mixed with different grade size of aggregates ,and the different percentage of sawdust partially replacement of the active filler i.e crushed stone dust 0 ;30;50;70;100 percent then subjected to marshal test apparatus to determine the behavior of the mixture in terms of flow and stability ,air voids VMA . These tests are performed before the aggregates tests have been performed such as sieve, aggregate impact, flakiness and elongation for the purpose of knowing the texture and the strength and durability of the aggregates material in the mixture.

Aggregate physical and mechanical test performed procedures:

3.2.1 Sieve analysis

The test was performed to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregates on different sieves as standardized and then passes aggregates through them and thus collects different sized particles left over different sieves.

Apparatus:

- A set of sieve of different sizes
- Balance with an accuracy to 0.1g
- Oven

The sample for sieving should be prepared from the larger sample either by quartering or by means of a sample divider.

PROCEDURE:

- ✓ The test sample is washed to remove all impurities.
- ✓ The test sample is dried to a constant weight at a temperature of 110 ± 5^{o}c and weighed.
- ✓ The sample is sieved by using a set of sieves
- ✓ On completion of sieving, the material on each sieve is weighed
- ✓ Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight.

The sample for sieving should be prepared from the larger sample either by quartering or by means of a sample divider.

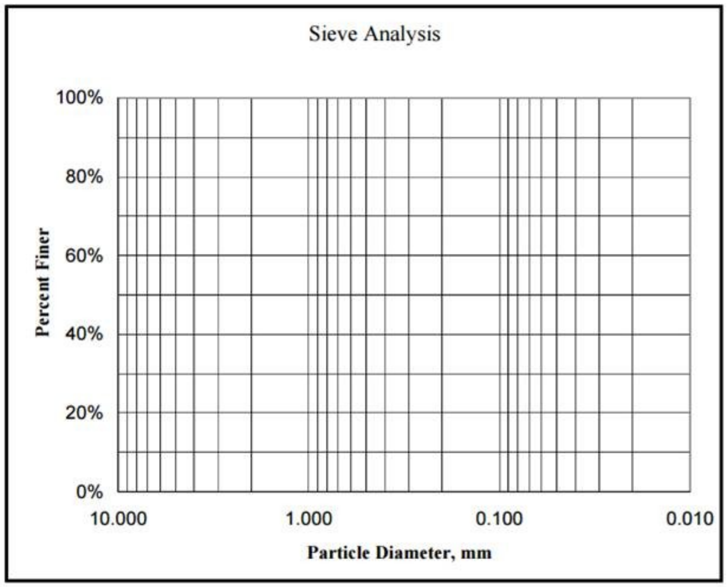
PROCEDURE:

- ✓ The test sample is washed to remove all impurities.
- ✓ The test sample is dried to a constant weight at a temperature of 110 ± 5^{o}c and weighed.
- ✓ The sample is sieved by using a set of sieves
- ✓ On completion of sieving, the material on each sieve is weighed
- ✓ Cumulative weight passing through each sieve is calculated as a percentage of the total sample weight
- ✓ Fineness modulus is obtained by adding cumulative percentage of aggregate retained at each sieve and dividing the sum by 100.

Calculation and reporting

The results shall be calculated and reported as the cumulative percentage by weight of the total sample then the percentage by weight of the total sample passing through one sieve and retained on the next smaller sieve, to the nearest 0.1 percent.

The results of sieve analysis must be recorded on a semi log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate. The Figure 16 shows the sieve analysis graph.



Graph sheet sample

Figure 16: Sieve analysis log- graph

3.2.2Aggregate impact value (AIV)

3.2.2.1 Theory

Impact value of an aggregate is the percentage loss of particles passing 2.36mm sieve by the application or load by means of 15 blows of standard hammer and drop, under specified test condition. The aggregate impact value gives a relative measure of resistance of an aggregate to sudden shock or impact, which in some aggregate differs from their resistance to the slowly applied compressive load.

The property of a material to resist impact is known as toughness (Fleck and smith, 1984). Due to movement of vehicles on the road the aggregates are subjected to impact resulting in their breaking down into smaller pieces. The aggregates should therefore have sufficient toughness to resist their disintegration due to impact. This characteristic is measured by impact value test. The aggregate impact value is a measure of resistance to sudden impact or shock, which may differ from its resistance to gradually applied compressive load (Taylor,1985).

AIM:

(i) To determine the impact value of the road aggregates;

(ii) To assess their suitability in road construction on the basis of impact value.

Apparatus

The apparatus as per IS: 2386 (Part IV) – 1963 consists of:

(i) A testing machine weighing 45 to 60 kg and having a metal base with a painted lower surface of not less than 30 cm in diameter. It is supported on level and plane concrete floor of minimum 45 cm thickness. The machine should also have provisions for fixing its base.

(ii) A cylindrical steel cup of internal diameter 102 mm, depth 50 mm and minimum thickness 6.3 mm.

(iii) A metal hammer weighing 13.5 to 14.0 kg the lower end being cylindrical in shape, 50 mm long, 100.0 mm in diameter, with a 2 mm chamfer at the lower edge and case hardened. The hammer should slide freely between vertical guides and be concentric with the cup. Free fall of hammer should be within 380±5 mm.

(iv) A cylindrical metal measure having internal diameter 75 mm and depth 50 mm for measuring aggregates.

(v) Tamping rod 10 mm in diameter and 230 mm long, rounded at one end.

(vi) A balance of capacity not less than 500g, readable and accurate upto 0.1 g.

Procedure

The test sample consists of aggregates sized 10.0 mm 12.5 mm. Aggregates may be dried by heating at 100-110° C for a period of 4 hours and cooled.

(i) Sieve the material through 12.5 mm and 10.0mm IS sieves. The aggregates

Passing through 12.5mm sieve and retained on 10.0mm sieve comprises the test material.

(ii) Pour the aggregates to fill about just 1/3 rd depth of measuring cylinder.

(iii) Compact the material by giving 25 gentle blows with the rounded end of the tamping rod.

(iv) Add two more layers in similar manner, so that cylinder is full.

(v) Strike off the surplus aggregates.

(vi) Determine the net weight of the aggregates to the nearest gram(W).

(vii) Bring the impact machine to rest without wedging or packing up on the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical.

(viii) Fix the cup firmly in position on the base of machine and place whole of the test

sample in it and compact by giving 25 gentle strokes with tamping rod.

(ix) Raise the hammer until its lower face is 380 mm above the surface of aggregate sample in the cup and allow it to fall freely on the aggregate sample. Give 15 such blows at an interval of not less than one second between successive falls.

(x) Remove the crushed aggregate from the cup and sieve it through 2.36 mm IS sieves until no further significant amount passes in one minute. Weigh the fraction passing the sieve to an accuracy of 1 gm. Also, weigh the fraction retained in the sieve.

Compute the aggregate impact value. The mean of two observations, rounded to nearest whole number is reported as the Aggregate Impact Value.

- Observation

Total weight of dry sample (W1) in grams

Weight of portion passing 2.36 mm sieve (W2) in grams

Aggregate impact value is shown in the equation 1 below in terms of percentage

$$= \frac{W2}{W1} * 100$$

Eq.1

The mean of two samples are considered and there are recommended value following the classification of aggregate using the Aggregate Impact Value (AIV).The Table 6 below is showing the recommended value of AIV. The classification and the values are considered in order make a decision making in regard to the strength of aggregate chosen for road construction .in fact this values help to carry out the standardize report whereby the results may be accepted or rejected .

The quality of aggregate will pray a big role in asphalt mixture that it simulate the behavior of the surface course one of the important layer that carry the most of the load imposed . such as traffic load the load is transmitted through surface course to be distribute to other respective layers base,subbase and subgrade (AASHTO,1993).Table 6 below shows the recommended values for Aggregate Impact Value .

Table 6: Recommended value of AIV

Aggregate impact value	Classification
>10 %	Exceptional strong
10-20%	Strong
20-30 %	Satisfactory for road surfacing
<35%	Weak

-

3.2.3 Flakiness index test

This method is based on the classification of aggregate particles as flaky when have a thickness (smaller dimension) of less than 0.6 of their nominal size, this size being taken as the mean of the limiting sieve apertures used for determining the size fraction in which the particle occurs(IS2386.part I ,1963).

The flakiness index of aggregate sample is found by separating the flaky particles and expressing their mass as a percentage of the sample tested.

The taste is not applicable to material passing a 6.3mm BS test sieve.

- Apparatus

A metal thickness gauge or special sieves having elongated apertures. The width of the apertures and thickness of the sheet used in the gauge or sieve shall be as specified. The figure17 shows the elongation and flakiness apparatus used to carry out the test of shape, texture of aggregate chosen to be used for the mixture in asphalt pavement. The performance is measure in terms of surface texture, i.e riding quality, international roughness index. When make asphalt mixture also intend to find the state of the surface with regard to the deformation and rutting explained by the two parameters such as stability and flow so the shape of aggregate will determine the bond, the adherence between the bitumen and the aggregate, the result of good performance of the surface layer structure. The flexible pavement has the quality of resisting water penetration into the structure due to its bond between bitumen and aggregates with specified shapes that is important in structural pavement design (Theyse, 2000).The Figure 17 shows the apparatus used to measure the flakiness and elongation in the laboratory.

Figure 17: Elongation and Flakiness apparatus

Thickness and length of gauge as BS test sieve is shown in the following Table 7 below.

Table 7: Thickness and length according to BS test sieve

Aggregate size fraction BS test sieve nominal aperture size		Thickness of gauge width of slots	Length gauge Gap pin between.	Minimum mass for subdivision
100% passing(mm)	100% retained(mm)	Mm	Mm	Kg
63.0	50.0	33.9±0.3		
50.0	37.5	26.3±0.3	78.7±0.3	35
37.5	28.0	19.7±0.3	59.9±0.3	15
28.0	20.0	14.4±0.15	43.2±03	5
20.0	14.0	10.2±015	30.6±0.3	2
14.0	10.0	7.2±0.1	21.6±0.3	1
10.0	6.30	4.9±0.1	14.7±0.2	0.5

A balance with the accuracy of 0.1 % of the mass of the sample is used.

- Procedure

✓ Carrying out a sieve analysis as indicated on the above table

✓ Discard all aggregate retained on the 63.0mm BS sieve and all aggregate passing 6.3mm BS test sieve.

✓ Weight each of the individual size fractions retained on the sieves other than the 63.0mm BS test sieve and store them on separate trays sizes marked on the trays.

✓ From the sums of the masses (M1) calculate the individual percentage retained on each of the various sieves. Discard any fraction of which the mass is 5% or less of the mass (W1).record the mass remaining (M2) .Gauge each fraction by on the following procedures:

✓ Combine and weigh all particles passing the gauges or special sieves (M3).

The equation 2 is shown below for the calculation of flakiness index.

- Calculation

$$= \frac{W3}{W2} * 100 \qquad \text{Eq.2}$$

3.2.4 Elongation index test

This test is based on the classification of aggregates particles as elongated when they have a length (greater dimension of more 1.8 of their nominal size being taken as the mean of the limiting aperture used for determining the size fraction in which the particles occurs (Bouquet,2006).

The elongation of particles and expressing their mass as a percentage of the mass of the sample tested. The test is not applicable to material passing 6.3mm BS sieve or retained on a 6.3mm BS sieve.

Apparatus

- A metal length with gauge length
- BS test sieves
- A balance to 0.1% of the mass to be tested

PROCEDURE:

✓ Carry out a sieve analysis using the sieves

✓ Discard all aggregate retained on a 6.3mm BS sieve and all aggregates passing a 50.0mm BS sieve.

✓ Weigh and store each individual size-fraction retained on the other sieves in separate trays with their sizes marked on the tray.

✓ From the sum of the masses of fractions in trays (M_1) calculate individual percentages retained of each the various sieves. Discard any fraction whose mass is 5% or less of mass (M_2)

✓ Gauge each fraction as follows;

✓ Select the length gauge appropriate to the size fraction under test and gauge each particle separately by hand.

✓ Elongated particles are those whose greatest dimension prevents them from passing through the gauge.

Combine and weigh all elongated particles (M_3)

Calculation of elongation index is calculated in the equation that follows in equation 2 below

$$= \frac{M1}{M2} * 100 \qquad \text{Eq.3}$$

Where by the M_1 and M_2 are discussed above.

3.2.5 Bitumen tests

3.2.5.1. Bitumen extraction test method

The Figure18 below is the sample of reclaimed asphalt in the laboratory to be used for the extraction of bitumen in order to determine the bitumen content. These are the samples obtained from KMH (Kanombe Miltary Hospital) a section of road rehabilitated using in place recycling technology with sand base. By NPD-COTRACO.

Figure 18 Reclaimed asphalt pavement sample

The process of extracting is done by centrifugal method where the aggregate should be separated with bitumen using the reactant called dichlomethane, is a liquid poured into the mass and in the equipment and close, after the equipment is put on and the materials inside are revolved and increase gradually to a maximum of 3600 rpm. The Figure 19 below is the sample after extraction in the equipment.

Figure 19: Sample after extraction in the equipment

This test was performed in the asphalt and bitumen laboratory in College of Science and Technology (CST), University of Rwanda .Its purpose was to determine the bitumen content in the reclaimed asphalt pavement brought for the research, and then RAP were to be as the original aggregate to be used in the marshal test and the mineral filler (crushed stone dust) were replaced by the sawdust ash and cement by 0;30;50;70 and100 percent in order to balance between the density of sawdust ash that has lighter density of 1.18 . The figure 20 below shows the RAP in the container.

Figure 20 sample of RAP after extraction

Test procedure

Fill the dichlomethane as dissolvent into the cup up to the sample top (as thoroughly soaked) . the dichlomethane will separate the aggregate and bitumen . Now place the filter paper and cover the sample in the centrifuge apparatus .Now place the container at the outlet of the centrifuge to collect the extracted sample.

This test is important because the various pavement properties such as durability, compatibility and resistance to various defects and failure such as Raveling, Rutting, bleeding depend upon the content of the bitumen present in the aggregate. The Table 8 below illustrates the observation and calculation sample of bitumen extraction.

Table 8: Observation and calculation

SN	OBSERVATION	SAMPLE 1	SAMPLE2	SAMPLE 3
1	Weight before extraction W1			
2	Weight of filter paper before extraction B			
3	Weight after extraction W2			
4	Weight of filter paper after extraction D			
5	Weight of filler collected in filter paper(B-D)=W3			

The formula to calculate the percentage of binder content is given by

$$= \frac{W1 - (W2 + W3)}{W1} X100 \qquad \text{Eq.3}$$

3.2.5.2 Penetration test

Penetration test is done to determine the penetration grade of bitumen in order to assess the consistency of the bitumen regarding their performance on the particular climate of the specified region (Bala, 2007).

The principle is that, the penetration of a bituminous material is the distance in tenth of a millimeter that a standard needle would penetrate vertically into a sample of the material under standard conditions of temperature, load and time.

Apparatus

- Penetrometer with a standard needle
- Three sample cup about 55 mm diameter and 35 deep each
- Water bath
- Thermometer 0 to 44^{0}c graduation 0.2 ^{0}c

Sample preparation

Bitumen should be just sufficient to fill the container to a depth of at least 15mm in excess of the expected penetration.

Procedure

1. Soften the bitumen above the softening point (between 75 and 100 ^{0}c). Stir it thoroughly to remove air bubbles and water.
2. Pour it into container to a depth of at least 15 mm in excess of the expected penetration
3. Cool it at an atmospheric temperature of 15 to 30 ^{0}c for one hour and half. Then place it in a transfer dish in the water bath at 25^{0}c +0.1^{0}c for one hour and a half.
4. Keep the container on the stand of the penetration apparatus
5. Adjust the needle to make a contact with the surface of the sample.
6. Adjust the dial reading to zero
7. With the help of the timer ,release the needle for exactly for 5 seconds
8. Record the dial reading
9. Repeat the above procedure three times

The value of penetration reported should be the mean of not less than three determinations expressed in tenths of mm.

3.2.6 Marshal stability and flow test procedure

This test is designed to determine the ability of the asphalt mixture to withstand the deformation defect due to the load caused by the wheel truck (ASTM D6927,1985).

Procedure

The sample should be of 1200 gr of the dry aggregates (RAP) extracted from bitumen, coarse aggregate, fine aggregates, filler and the percentage bitumen of 4, 4.5; 5; 5.5 and 6 percent respectively. The aggregate should be heated to 160^0c. The heated aggregate was placed in a pan and mixed thoroughly. A crater was formed in the aggregate and the 79 penetration grade bitumen heated to 160^0c was added. The aggregate and the bitumen were mixed thoroughly until the RAP aggregates were well coated ,then thoroughly cleaned sample mold assembly and the compaction hammer was heated to 160^0c.

A filter paper was placed in the bottom of the mold and the mixture was placed in the mold and trimmed with a spatula around the perimeter. The collar was removed and the surface of the mix was smoothened with a trowel to a slightly rounded shape. Temperature of the mixture immediately prior to compaction was maintained at 150^0c in the oven. The collar was replaced, and the mold assembly was placed on the compaction pedestal in the mold holder, and the top of the specimen was given 65 blows. The baseplate and the collar were removed and the sample was inverted and the mold reassembled. The inverted face was also given 65 blows. After compaction, the baseplate was removed and the mold containing the specimen was immersed in cool water for two minutes .The specimen was removed from the mold by the means of sample extractor and a suitable jack and flame arrangement .The specimen was placed on a smooth, flat surface and allowed to cool at room temperature for 24 hours.

3.2.7 Density determination

The specimen was weighed in air and in clean water at a room temperature, the percent density or percent compaction is the ratio of the actual Ga of the compacted bituminous mixture specimen to the theoretical maximum specific gravity of the combined aggregates and asphalt contained in the specimen expressed as a percentage, density is calculated as follows in Kg/m^3

The calculation of density is calculated as taking the mass of briquet (A) divide by the difference of saturated surface dry (B) and the mass of briquet in water (C) .

$$Ga = \frac{A}{B - C} \quad \text{eq.1}$$

3.2.8 Specific gravity

Specific gravity will be determined for every single component of the asphaltic mixture such as coarse aggregate, fine aggregate, cement and sawdust ash(SDA) these last are filler as well as the specific gravity of stone dust as the control sample as the ordinary filler in the mix.

Specific gravity procedure

The specific gravity is computed as the ratio of the weight in air of a given volume of soil particles at a stated temperature to the weight in air of an equal volume of distilled water at the same temperature.

-Coarse aggregate specific gravity is needed to determine weight- to -volume relationships and to calculate various volume related quantities such as Voids in Mineral Aggregate (VMA) ,and Voids Filled by Asphalt (VFA) ,and also is normally used in construction ranges from 2.5 to 3.0 with an average value of about 2.68 , specific gravity is an indication of strength means that material having higher specific gravity is generally considered as having higher strength.

-cement will also have to be tested for specific gravity as it is going to be assessed in terms of mixture proportion to know the behavior of the material in water. The specific gravity of Portland cement is generally around 3.15 while the specific gravity of Portland-blast furnace slag and Portland –pozzolan cements may have specific gravities near 2.90 (PCA ,1988).

-sawdust ash

Sawdust ash has a specific gravity of 1.18 and PH 9.5, dry extract by mass of 40%

3.2.9 Stability and flow determination

The sample was brought to test temperature by immersing in water bath for 20 to 40 minutes .The sample was properly put into the test breaking head .The upper segment of the breaking head was placed on the specimen and the complete assembly was placed in the position on the testing equipment. The flow and stability are read automatically on the machine after that the load was released then the stability and flow were to be recorded on the start of breaking of the specimen, the marshal stability machine with the specimen in place is shown in Figure 21 below.

Figure 21: Marshall Stability testing machine

All experiments procedures are carried out in accordance to the standards specifications ASTM C618 -92a, 1994. Various proportions of sawdust ash (SDA) passing through sieve No. 200 and in equal proportion with cement were stabilized with various RAP aggregates (the appropriate peak proportions was however determined during the preliminary mix design tests). The RAP used was crushed using LOS Abrasion from its state to smaller particle sizes ,passed through a 28mm aperture sieve was air dried and sieved after they are mixed with bitumen in percent, up to 6 percent as bitumen percentage, 20 samples with 450 gr. of the fines to be in a different proportion as seen below:

Sample 1: 4%; 5%; 5.5; 6% bitumen with 100 percent SDA as filler

Sample 2: 4%; 5% 5.5%.; 6% bitumen with 70 percent SDA as filler

Sample 3: 4%; 5%, 5.5%;6% bitumen with 50 percent SDA as filler

Sample 4: 4%; 5%; 5.5%; 6% bitumen with 30 percent SDA as filler

Sample 5: 4%; 5%; 5.5%; 6% bitumen with 0 percent SDA as filler and 100 percent crushed stone dust (CSD)

The masses required were also determined to ease the calculation of bulk specific gravity and other parameter

The core was organized as follows to determine the specific gravity of each sample at the optimum binder of 5%. The table 9 below following the formula eq.1

Table 9: specific gravity

Mass of samples in air(gr.)	Mass of samples in water (gr)	Saturated dry	Bulk specific grav.
1201gr	665.4gr	1228gr	2.15
1202gr	672.1gr	1211gr	2.17
1200gr	671gr	1213 gr	2.21
1203gr	668gr	1222gr	2.17
1202gr	671gr	1220gr	2.12

CHAPTER4: RESULTS AND DISCUSSION

4.1 BITUMEN EXTRACTION TEST RESULTS

In this study the use of sawdust ash stabilization on the reclaimed asphalt pavement (RAP) ,to assess the behavior of the sawdust ash in the asphalt mix composed of different percentage replacement of the crushed stone dust as filler(CSD) have been investigated and studied via experimental driven data . The results of three samples from laboratory are presented through the tables and figures respectively. Example below is the presentation of results of first experiment in form of table that is Table 10. This test is performed according to EN 12697-1

Sample A

Table 10: Bitumen extraction results sample A

A	Weight of asphalt in gr.	552.0
B	Weight of empty Aluminium cup in gr.	258.0
C	Weight of aluminum cup with filler in gr.	288.6
D	Weight of aggregate recovered on sieve in gr.	483.0
E	Weight of filler recovered in gr.(C-B)	30.6
F	**TOTAL weight of aggregates in gr.(D+E)**	**513.6**
G	Weight of bitumen extracted in gr.(A-F)	38.4
	Bitumen content ((G/F)*100)	7.5

The percentage of bitumen content present in the first sample of 552gr pavement is 7.5 Percent bitumen in old asphalt concrete at the section Kanombe Military Hospital (KMH).

Particles size distribution: particle size distribution or sieve analysis of coarse –grained particles (sand and gravel fraction) was carried out in order to group the particles into separate ranges of sizes and to determine the relative proportion by mass of each size range. To achieve this sample/stabilized sample was passed through successively smaller mesh sizes. The weight of asphalt concrete crushed sample retained on each sieve was calculated. Furthermore the particle size distribution was compared through results obtained with virgin aggregate and sand base of the road in a case study KMH.

As we have discussed for the experiment above of knowing the bitumen content in the sample A the following sample B is also to determine its bitumen content through extraction the variables are to be three to provide the good results as the experiment results shows in the Table 11 below .

Table 11: Bitumen extraction results sample B

A	Weight of asphalt in gr.	652.0

B	Weight of empty aluminium cup in gr.	258.0
C	Weight of aluminum cup with filler in gr.	288.6
D	Weight of aggregate recovered on sieve in gr.	583.0
E	Weight of filler recovered in gr.(C-B)	30.6
F	TOTAL weight of aggregates in gr.(D+E)	613.6
G	Weight of bitumen extracted in gr.(A-F)	39.0
	Bitumen content ((G/F)*100)	6.3

The following Table 11 is also discussing the results of bitumen extraction sample C where by the results are quite similar to the first and second extraction bitumen percentage due to the design procedure done before the analysis period and design period this determine the life cycle , maintenance and rehabilitation strategy of the country through pavement condition and time. The results are of great importance because the RAP to be used are not enough impregnated by the bitumen though recycling is simple and viable to be sustainable during the execution period in regard of rehabilitation and maintenance.

The Table 12 below shows the bitumen extraction for the samples C extracted during the test and the bitumen content of 4.7

Table12: Bitumen extraction sample C

A	Weight of asphalt in gr.	582.0
B	Weight of empty aluminium cup in gr.	258.0
C	Weight of aluminum cup with filler in gr.	288.6
D	Weight of aggregate recovered on sieve in gr.	525.3
E	Weight of filler recovered in gr.(C-B)	30.6
F	**TOTAL weight of aggregates in gr.(D+E)**	**555.6**
G	Weight of bitumen extracted in gr.(A-F)	26.4
	Bitumen content ((G/F)*100)	4.7

The summary below is the average bitumen percentage of the KMH road by recycling sand base application executed by NPD –COTRACO where the average is understandable and the RAP can be useful in terms of gradation as the objective of extraction. The summary of the results shows the compilation of the samples from A, B and C where the results are 7.4; 6.2 and 4.7 respectively. The average shows give 6.2 percentage bitumen content in the sample obtained from the field by milling

The summary of the results are illustrated in the Table 13 below

Table 13: Summary

Samples	**A**	**B**	**C**
%bitumen	**7.4**	**6.2**	**4.7**
Average			**6.2**

Considering the percentage of bitumen varying according to the location of sample extracted, sample was extracted in center line of the rehabilitated road KMH and sample B at the verge of

on of the binder was to

p in the mixture. The

as the material in the

content distribution for

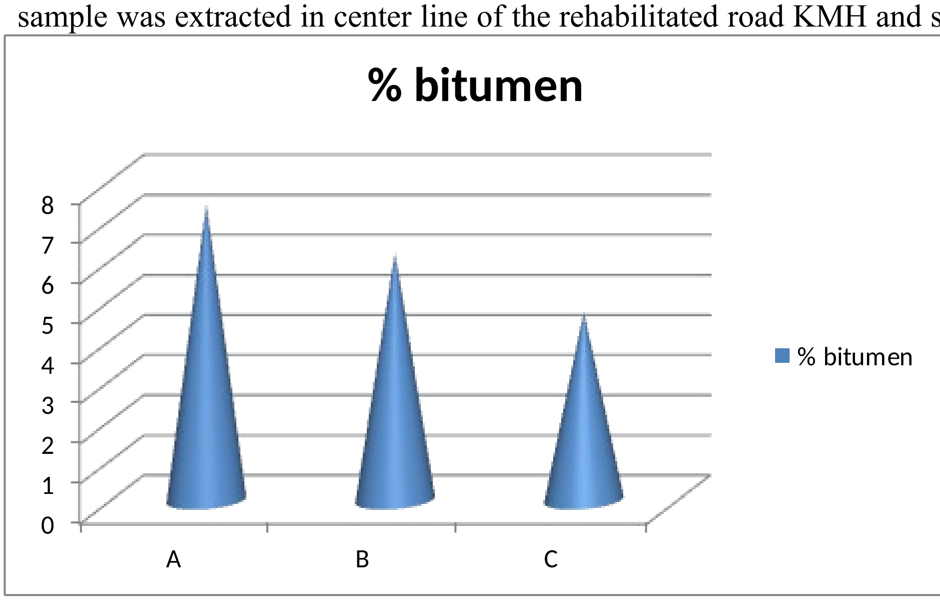


Figure 22: Bitumen content distribution

The Figure 23 below shows the average percentage of the bitumen extracted for three samples

Showing how the average is behaving, the bitumen content found show that the aggregate were coated enough first sample.

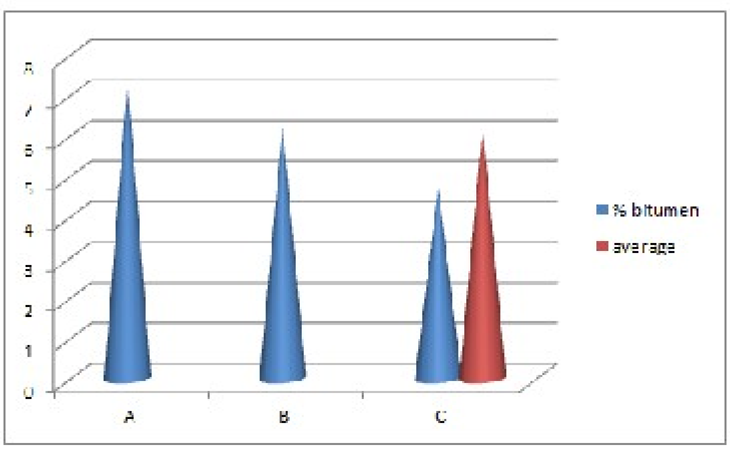


Figure 23: Average bitumen content in percentage

4.1.1 AGGREGATE TESTING RESULTS

Aggregate testing of RAP extracted of bitumen has been conducted in laboratory including physical test such as particle size distribution. This is a fundamental property, which governs how an aggregate will perform in the mixture.

The aggregates tests include sieve analysis where by the gradation will be examined, percentage passing is of great importance, because the durability of an aggregate it's a measure of its ability to resist deterioration in service and so retain its original grading ,shape and physico mechanical properties during the service of the road.

The good mixture with bitumen and well graded particles contribute to the strength of the pavement which shows the resistance to the deterioration at early age due to traffic loading, and environmental effect such as climate, rain water which penetrate within the bond.

4.1.1.1 Sieve analysis for sample A

This experiment is performed according to EN 933-1 specification and the sample A are obtained from aggregate separated by using bitumen extraction test sample A as well, the sample A is weighing 483 grams. The Table 13 below show the gradation of the aggregates that even there are of reusing purpose they show the well graded sample to be used without any other supplement of aggregate as it is shown for the purpose of asphalt mixture the presence of coarse and fine aggregate required.

Table 14: Sieve analysis data

Sieve (mm)	Cumulative retained (g)	%passing
20	0.0	**100.0**
16	0.0	**100.0**
14	0.0	**100.0**
12.5	3.0	**99.4**
10	34.0	**93.4**
8	68.0	**86.8**

6.3	126.0	**75.5**
4	266.0	**48.2**
2	336.0	**34.6**
1	372.0	**27.6**
0.5	407.0	**20.8**
0.315	432.0	**15.9**
0.25	443.0	**13.7**
0.08	483.0	**6.0**

The Figure 24 that follows shows the result in terms of log-graph it goes with the first sample of aggregate 483grams. The graph is showing the well graded sample as it is given in the previous table of gradation of the first sample A

Graph of particle size distribution sample A

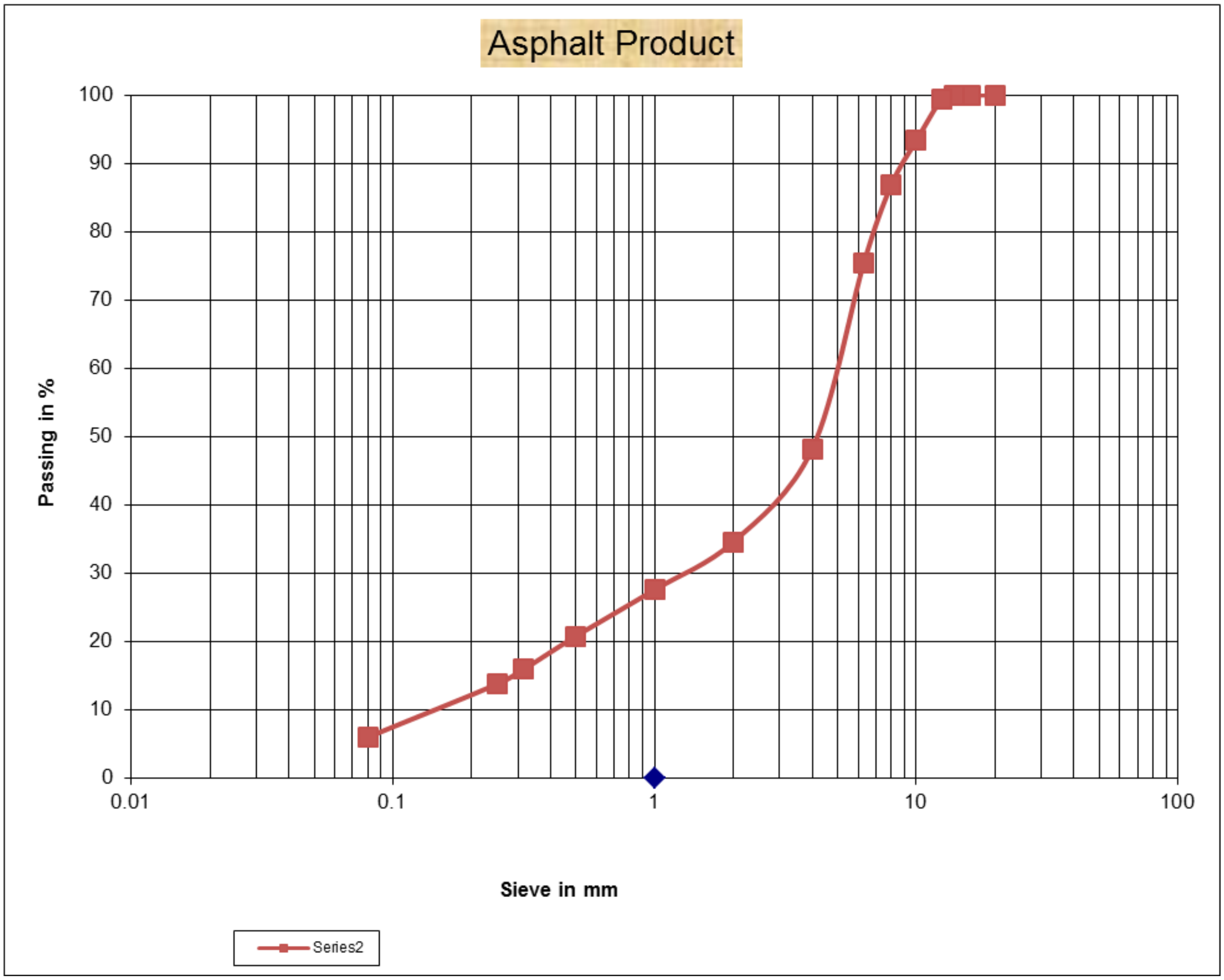


Figure 24: Sieve analysis graph A

As we have three samples previously now the sieve analysis is done to the second sample of aggregate extracted from bitumen by the extraction method as it was done by centrifuge, the Table 14 below shows also the gradation of RAP aggregates those are showing the well graded as we can see on the log graph after word.

Table 15: Sieve analysis data B

Sieve (mm)	**Cumulative retained (g)**	**%passing**
20	0.0	**100.0**
16	0.0	**100.0**
14	0.0	**100.0**

12.5	3.0	**98.9**
10	34.0	**89.9**
8	68.0	**81.0**
6.3	126.0	**69.6**
4	266.0	**46.8**
2	336.0	**33.8**
1	372.0	**28.8**
0.5	407.0	**22.6**
0.315	432.0	**13.5**
0.25	443.0	**7.4**
0.08	483.0	**4.8**

The Figure 25 below is the log-graph of the second sample respectively as it done methodologically from first sample, the result are shown in terms of sieve analysis graph this graph is showing the well graded aggregate to be used in the mix of asphalt as it is the objective of this research which is to determine marshal stability and flow of the mix by replacing the crushed stone dust as filler (CSD),by sawdust ash and cement as filler material.

Graph of particle size distribution B

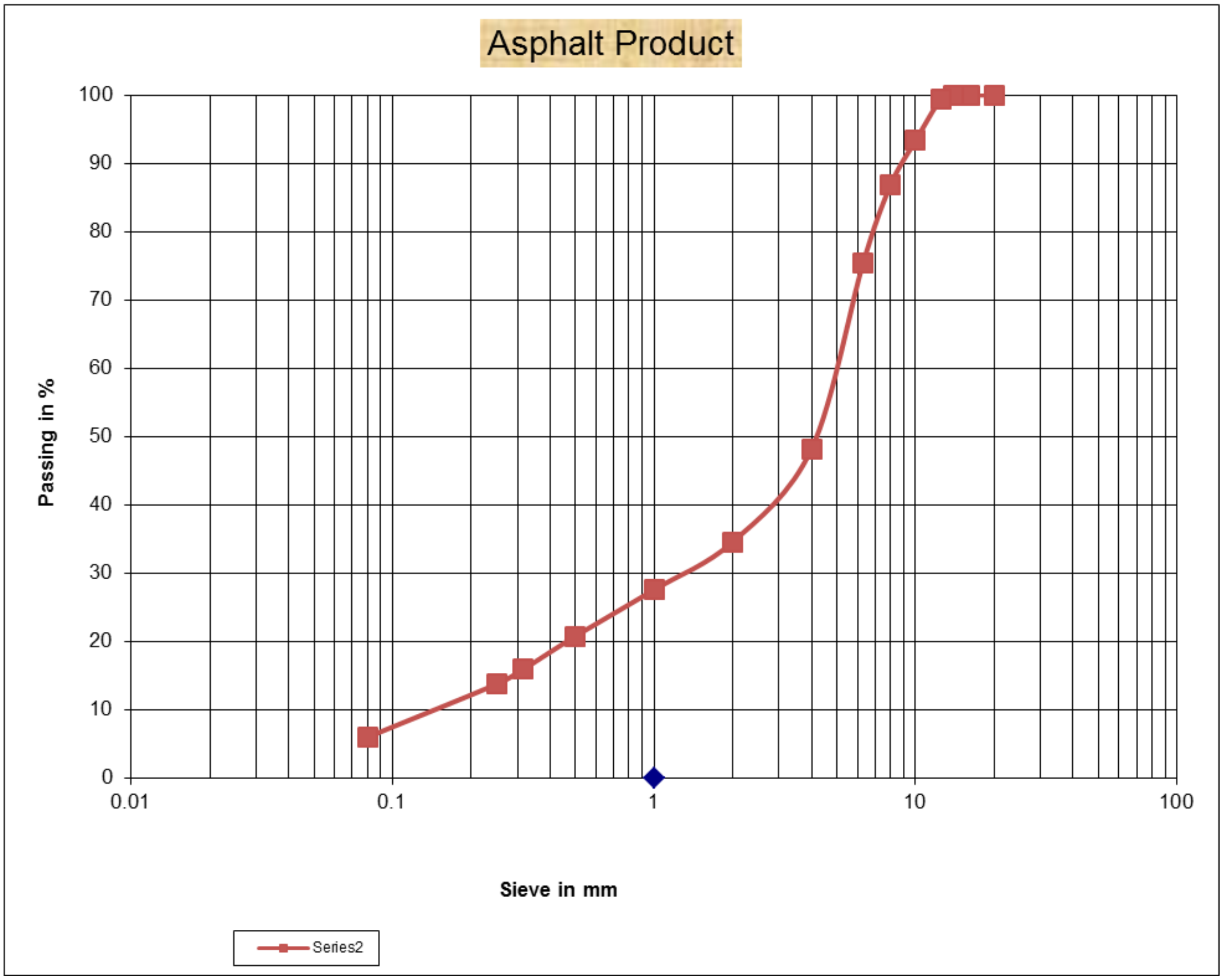


Figure 25: Sieve analysis graph B

The experiment that is following is to find also the sample number three, sample C to determine its gradation by separating the reused aggregate, the sample C also show the well graded behavior and it is well to be used in the mix. The Table 15 illustrates the sieve analysis for the aggregate extracted sample

Table16: Sieve analysis for the aggregate extracted sample

Sieve (mm)	**Cumulative retained (g)**	**%passing**
20	0.0	**100.0**
16	0.0	**100.0**
14	0.0	**100.0**
12.5	3.0	**100.0**
10	34.0	**94.7**
8	68.0	**86.7**
6.3	126.0	**76.8**
4	266.0	**53.3**
2	336.0	**37.2**
1	372.0	**28.5**
0.5	407.0	**17.8**
0.315	432.0	**14.9**
0.25	443.0	**8.3**
0.08	483.0	**5.3**

Sieve analysis graph according to EN 933-1 (passing in %) sample C is shown in Figure 24 below also well graded sample.

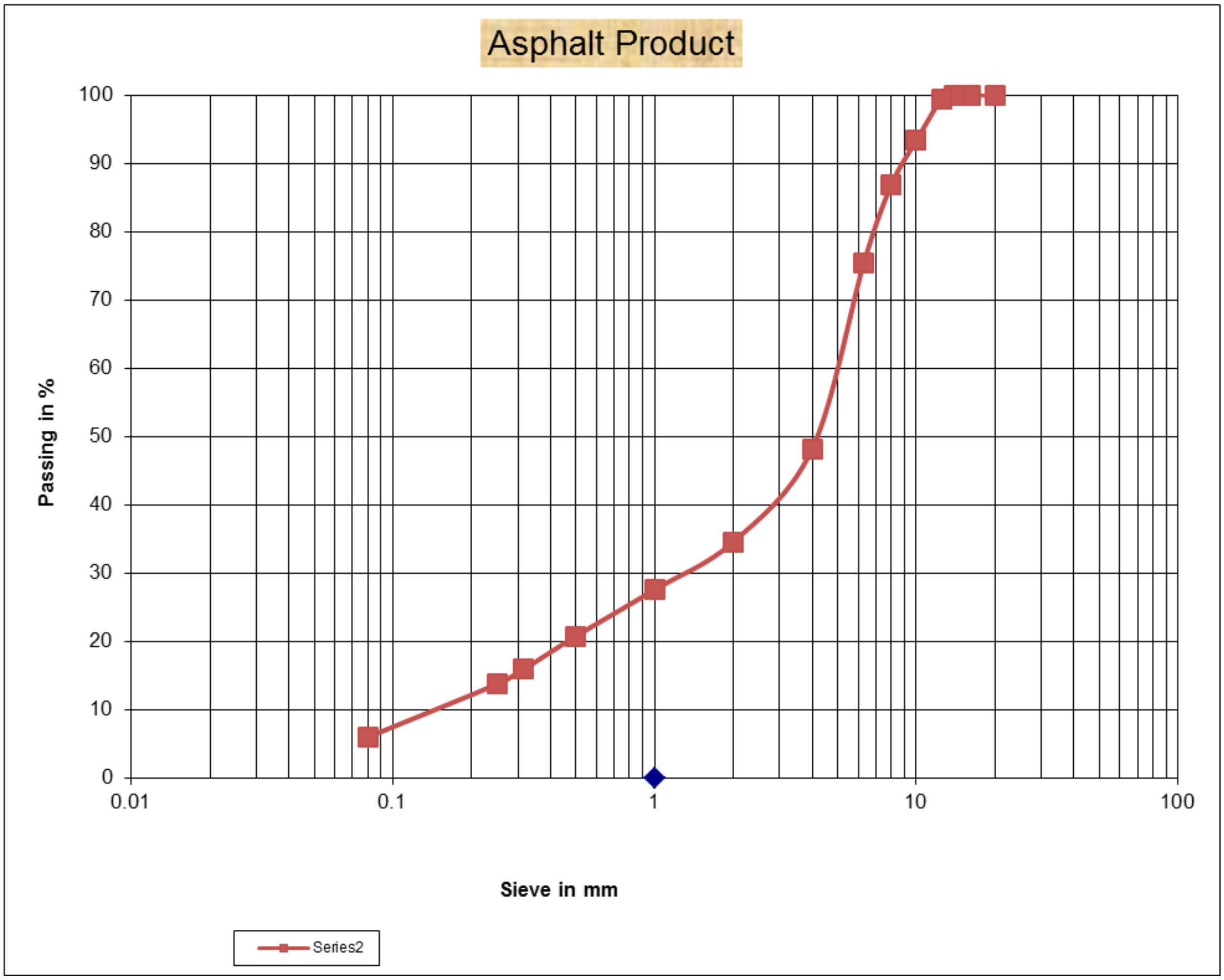


Figure 26: Sieve analysis graph C

Discussion summary of gradation

The previous chapter shows the gradation of RAP particles after extracting the bitumen, the results shows that all three samples take A,B and C were well graded particles .

The sign that the rehabilitation of the pave road will reuse the aggregate in place, which will be reclaimed, and stabilized with cement and saw dust as filler i.e crushed stone dust.

4.1.2 Aggregate particle shape

In both natural and crushed rock aggregate the particles within a particular size fraction have a range of shapes .the shape reflect intrinsic petrological –petrographic characteristics of the material, environmental effects plays a role in their formation and process.

BS 812:part 103: 1985 groups the aggregates particles into six shapes : rounded ,irregular, angular ,flaky, elongated and elongated or flaky.

a) Flakiness: This is restricted to aggregate coarser than 6.5 and is an expression of the weight –percentage of particles, in a minimum sample of 200 pieces, whose least dimension is 0.6 the mean dimension. The mean dimension is the arithmetic average of the side dimension of the delimiting square holed sieves.

b) Elongated: this is the weight percentage of particles whose long dimension is greater than eight times the mean dimension .measurement can be made with a standard gauge (BS 812: part 112: 1985). The table 16 shows the results found during the laboratory test.

Table 17: Flakiness index

Flakiness index							
Sieve(mm)	Slot gauge(mm)	Number of particles	Total weight(gr.)	Passing particles	Passing weight(gr)	Flakiness index by number %	Flakiness index by weight %
63-70	33.9						
50-37.5	26.23						
37.5-28	19.65						
28-20	14.4	100	1493.4	16	239.7	16	16.05
20-14	10.2	100	680.1	19	160.6	19	23.62
14-10	7.2	100	324.9	17	41.1	17	12.64
10-63	4.9						

						17	18

The Table 17 below is discussing the RAP used as the texture as the test for the good pavement materials the as it is shown through the results.

Table18: Elongation index

				Elongation index			
				Retained particle	Retained weight(gr)	Elongation index by number%	Elongation index by weight %
63-70							
50-37.5							
37.5-28							
28-20				8	43.2	8	2.89
20-14				16	176.1	16	25.9
14-10				14	142.8	14	43.94
10-63							
						13	14

The two Tables are describing the flakiness index and elongation index, the same condition of test, same sample, same sieve size and weight of sample.

4.2: Mechanical test

4.2.1 Aggregate impact value (AIV)

The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregates differs from its resistance to a slow compressive load it is classified as the strength test.

Calculation

The ratio of the weight of fines formed to the total sample weight in each test shall be expressed as a percentage the results being recorded to the first decimal place.

Aggregate Impact Value = (B/A) X 100 where A is weight in gr. of a saturated surface –dry sample while B is weight in gr. Of fraction passing through 2.36 mm IS Sieve.

The below Table 18 shows the value of aggregate impact value where by it is one of the indicator of durability measure of aggregate as part of mechanical test, the value shows the good behavior of the RAP to be used in the mixture for the pavement, the Marshall test will also prove the stability and flow of the mixture late alone.

As table of results is between 10 and 20, therefore the material is strong according to the specification and recommendation for the road materials.

Table19: Aggregate impact value (AIV)

Aggregate impact value test		
Standard Method IS - 2386 (Part IV)		
Test number	1	2
Weight of Cylinder + Sample(gr)	3222.4	3211.53
Weight of Cylinder (gr)	2617.04	2617.04
Total Mass of Sample(gr)	605.36	594.49
Retained Weight (gr)	484.6	489.73
Passing Weight (gr)	120.8	104.8
Aggregate Impact Value	19.9	17.6
Average aggregate Impact Value	19	

4.3 Bituminous mixture test

4.3.1 Marshal test and procedure

- First we take IS sieve set
- We sieve aggregates on sieves of size 12.5 mm; 10 mm;4.75 mm and 2.36 mm

- We sieve finer particle this time ,we will be using sieves of size 2.36 mm,600 µm,300 µm;150 µm;75 µm
- After sieving the total weight of aggregate is 1.2kg

The Figure 26 below shows the samples in oven ready for mix in order to perform the marshal test.

Figure 26: Sample in oven

Heating the aggregate to the temperature of 175-190 Celsius

Now we will add bitumen (4-6% by weight) heated up to 100-140 Celsius, in aggregates will mix it properly.

After mixing thoroughly, we will pour the mixture in the mold.

In the process we 65blows are utilized.

The Table 18 below shows the proportion in the mixture according to STM D (1559) the size used for the weight of aggregate and their corresponding sieve size. The results are sound and good to make a mixture.

Table20: Sample proportion for the mixture

Weight of aggregate	Size
71.5g	12.5 mm
331.5g	10 mm
103.5g	4.7 mm
223.5g	2.6 mm
450g	Filler(SDA)+cement

1200g	

Test procedure for marshal

1. Pre-heating of mold

2. Remove from the mold

Put it into hot water bath of 60 degree Celsius for 20 minutes

- Take the submerged weight after 20 min
- Fix the mold in breaking head
- Put the set up on the machine
- Adjust the screws and daily gauge
- Upper daily gauges gives stability reading
- Lower daily gauges gives flow value
- Remove the tested mold

The Table 20 below shows the standard description and requirement of the marshal test according to (ASTM Designation: D-1559) and the value of flow and stability IRC.

Table 21: Recommendation of marshal value and flow value as per IRC

S-N	Description	Requirement
1	Marshal stability (ASTM Designation :D-1559) Determined on marshal specimens compacted by 75blows on each end.	820 kg Minimum
2	Marshall flow (mm)	2-4
3	Percent voids in mix	3-5
4	Percent voids in mineral aggregates(VMA)	Minimum 11-13 percent
5	Percent voids in mineral aggregates filled with bitumen (VFB)	65-75
6	Binder content ,percent by weight of	Minimum 4.5

	total mix	

The Figure 27 below is showing the samples in laboratory in a tray and sample in the testing machine for stability and flow.

Figure 27: The sample in a marshal stability testing machine

The table 21 shows the results found during the test with their corresponding parameter for the mix of the bitumen percentage ranging from 4 up to 6 as the optimum bitumen content utilized in the mix the filler are sawdust ash and cement in the same proportion of 50% and the ordinary filler are completely replaced.

Table22: Values found during test

SN	%-Bitumen	Marshal stability value	Flow values	Bulk specific gravity (Gm)	Air voids (%Vv)	%of bitumen (Vb)	VMA	VFB
1	4	686	3.26	2.15	3.90	7.622	11.522	65.96
2	4.5	765	3.36	2.11	3.26	8.560	11.82	67.68
3	5	820	3.80	2.13	2.60	9.460	12.06	78.44
4	5.5	672	4.20	2.12	1.46	10.340	11.80	85.60
5	6	518	4.30	2.14	1.43	10.540	11.97	87.00

The graph below present the Figure 28 and it is showing the optimum bitumen as 5 percent for all proportion of the SDA for all five samples for each bitumen percentage whose stability is read against bitumen percentage. The samples cube are found in the appendix

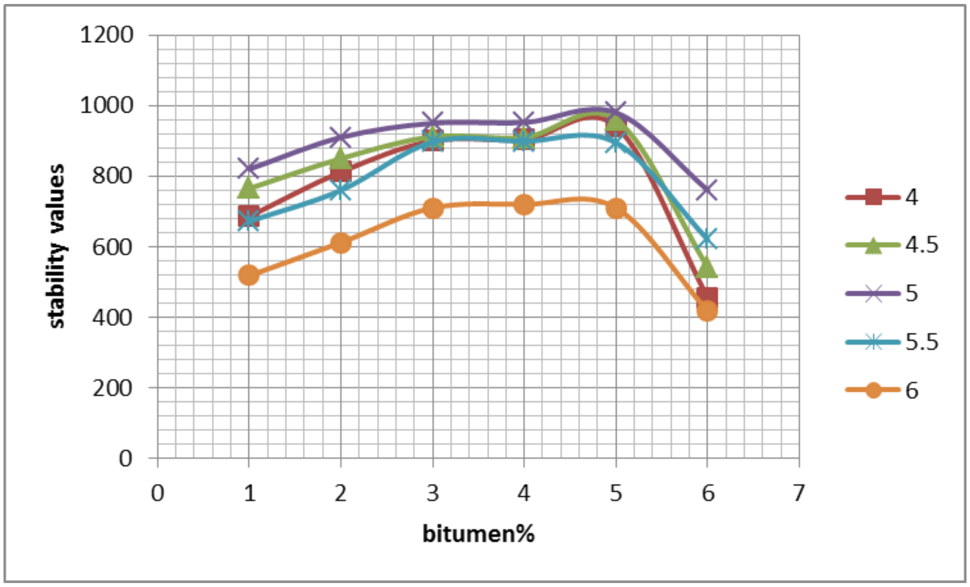


Figure 28: Bitumen content% vs Marshal Stability value

The Figure 29 below shows the values of flow in millimeter for all the samples for different percentage of SDA as presented in the matrix of samples page 51.

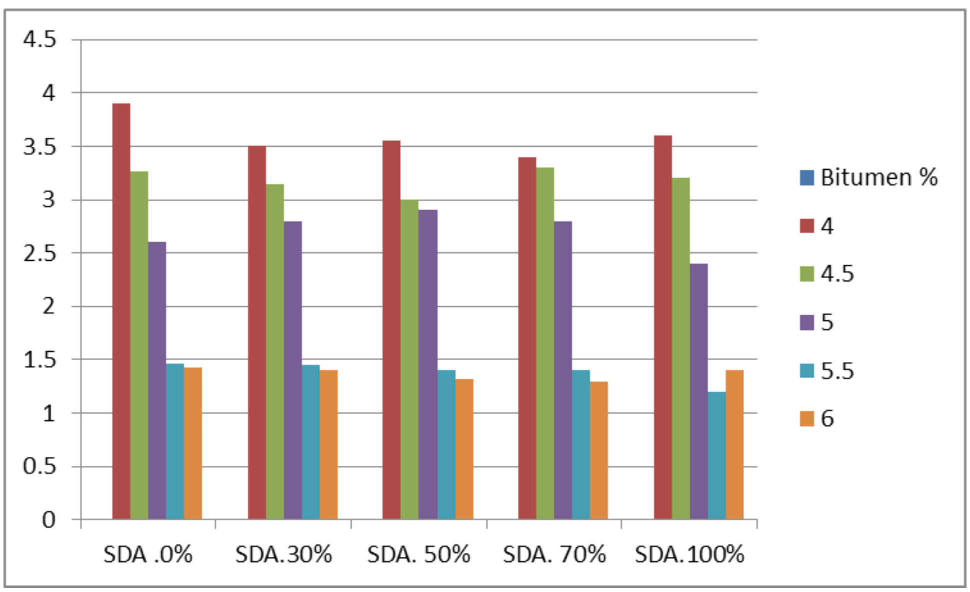


Figure 29: Bitumen % vs flow values

Discussion for the marshal test

The optimum content of the bitumen in the mixture is determined and shown in the graph above .The stability test results, the results show that the stability increases with the bitumen content % up to the optimum content and thereafter decreases.

The optimum bitumen content was found to be 5%, .the stability of the mix with sawdust ash and cement in equal proportion was found to be near the one with crushed stone dust (CSD) as the ordinary filler in the mixture.

At the optimum bitumen content of 4;5; 5.5 and 6 the stability were 6.48KN, 7.65KN,and 8.20 KN respectively .it can be noticed that the effect of sawdust and cement is huge because the stability values meet the AASHTO specification that is not going less than 3.5 KN . These results are considered and indicate that the asphalt mixture with SDA and cement have better stability as the ordinary filler especially on the 5% bitumen of the total weight of sample composed of sawdust ash at 90 percent and 10 percent crushed stone dust or mineral filler.

The better stability can be attributed to improved adhesion of between the aggregates and the bitumen as well as the sawdust ash. I would like to recommend the more test like indirect tensile fatigue, four point bending etc. for further research to confirm the behavior of sawdust ash in the mixture.

The flow values of the both asphalt mixtures against bitumen content are shown in the Figure 28 bitumen %vs flow values.

Flow values are the displacement expressed in mm the results were 3.2; 3.3; 3.8 and 4.2 for the first sample composed of 100 percent SDA and then the results were varied according to the percentage of SDA present , that shows the increase with the sawdust ash as attitude toward the mixture and the behavior of sawdust ash toward the binder. This manifest here the presence of the sawdust ash and cement, the surface become slightly cementitious i.e asphalt cement.

Stiffness of the bitumen (Sbit)

The bitumen utilized for the test in this study is for the temperature of 30 ^{o}c where is assumed to be performed in worm region. Bitumen properties have been set and they are as follows in the table 23 below

Table23: Bitumen characteristics and conditions

Bitumen properties	Penetration at 25^{0}c dmm
	79
Penetration index	-0.5

The results were as follows considering the data given above thus the following Table 8 illustrates the results of bitumen stiffness after the sawdust has been analyzed

At the penetration of 79 dmm, and also considering the temperature of between 20-30 the softening point was 48 according to the ring and ball test and also using the chart for determination of T_{800} and penetration index (PI).

Stiffness of the bitumen at a temperature of 30 degree Celsius the stiffness was 3.5 x10^6 pa which shows the effect of sawdust ash in the mix for the cube of 5percent bitumen and 70 percent SDA and 30 percent CSD. Stiffness of the mix (Smix) is in normal range it can be useful as the ordinal mineral filler in the pavement.

Here is the summary of the whole stiffness results on the table 8 below

Table 24: Stiffness of bitumen at temperature of 25 ^{0}c

	Sbit (Pa) 10^8				
	Proportion of SDA in the mix and RAP				
Bitumen %	10	30	50	70	100
4	0.8	0.9	1.3	0.8	0.4
5	0.9	0.95	1.5	0.7	0.3
5.5	1.1	1.0	1.9	0.5	0.26
6	1.2	1.3	2.1	0.3	0.4

- Bitumen is temperature sensitive. That why there is a significant reduction in bitumen stiffness for both bitumen at 30^{o}C sawdust demonstrates a change to the mix when bitumen percentage increase up to the optimum of 5 percent and as the quantity of sawdust increase the there is a significant change in the stiffness but at 50 percent.

Table 25: Stiffness of the mix

	Smix (Pa) 10^8				
	Proportion of SDA in the mix and RAP				
Bitumen %	10	30	50	70	100
4	0.7	0.9	1.6	0.8	0.4
5	0.75	0.95	1.8	0.7	0.3
5.5	1.2	1.0	1.9	0.5	0.26
6	1.3	1.3	2.3	0.3	0.4

- The stiffness of the mixture is increasing as the percentage of sawdust increase but now at the fifty percent
- The stiffness of the mixture do not only depends on the bitumen stiffness but also the voids, aggregate grading, aggregate shape, texture, and degree of compaction
- The stiffness of bitumen value is lower that the stiffness of mix value. This means that the aggregate structure influences the increase in stiffness. And also at higher temperatures the contribution of the aggregate structure increases.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The aim of this thesis is a study on the effect of sawdust ash in different proportion with active filler (CSD) in the asphalt mixture composed of reclaimed aggregates. The marshal test was used to assess the stability and flow of the asphalt mixture by using the sawdust ash (SDA) as the filler replacing the ordinary filler which is the crushed stone dust (CSD).The results were showed that the performance of the asphalt surface were effective as the ordinary filler application , in the asphaltic road construction and also the rehabilitation can be carried out by using recycling technology as RAP were used to be also effective in terms of usage as cost effective as virgin aggregate are expensive .

The use of RAP is better choice to be used road pavement and rehabilitation due to

- The good performance in terms of resistance to deformation
- Saw dust ash and cement can perform better for sub- base material as cementitious
- The proportion of bitumen used in the study were 4%, 5%, 5.5% and 6% were good to evaluate the stability where by the optimum bitumen content is 5% RAP with all the necessary quality control such the test of aggregate either physical and mechanical test for aggregates. When the new bitumen content is added we observe the increase of stability decrease of flow.

The tests performed were grading test i. e sieve analysis, also the mechanical test such as aggregate impact value which has proved that the RAP lies between 10 and 20 the RAP was satisfactorily to sustain the loading impose by the traffic .

- The surface was to be evaluated through marshal test which showed that it can perform well through IRI as the indicator of smoothness and surface texture.

5.2 Recommendation

The use of sawdust ash and cement in same proportion as stabilizers in road construction and rehabilitation and are very much useful.

As the developing country where the materials take huge amount of expenses, the researches of using local available materials have to be taken into consideration.

The industry of road construction worldwide is an important thing in the socio economic development therefore the investment in the sector is to be considered in the cost effective way by the strategy: planning, preparation and operation these are management of the project.

The sawdust ash and RAP usage will also address the problem of land fill i.e. problem of deposition of used waste in Rwanda example UDUKIRIRO, the sawdust obtained from carpenters will be an important solution.

I would recommend that all the sawdust waste should be well managed in terms of deposition for future works.

The same as the waste from the rehabilitation of paved road using conventional way, that waste should be reused in road pavement thus reducing the hazardous bituminous effect for the environment as well as the disposal problem stipulated previously in the text.

5.3 Areas of further studies

There still some areas in which detail study is required some of them are as follows:

- More study is needed to analyze the effect of sawdust ash on the permanent deformation of the surface
- Analysis of the characteristic of binder and its effect on the stiffness and aging

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APPENDICES

Appendices–A: RAP Collection

Appendices–B: Sawdust ash sample

Appendices–C: Binder extraction

APPENDICE A

RAP

APPENDICE B

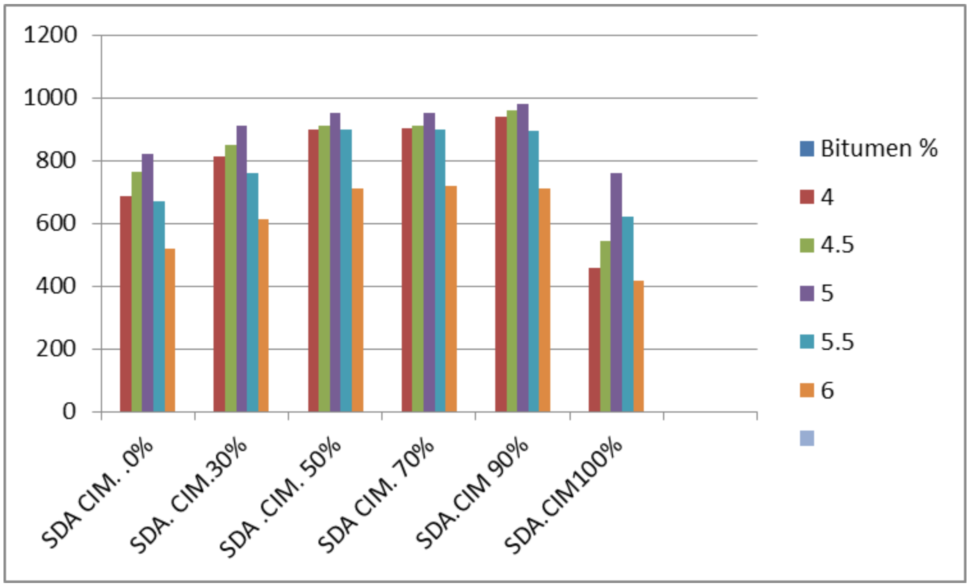
Sawdust ash sample

APPENDICE-C – binder extraction

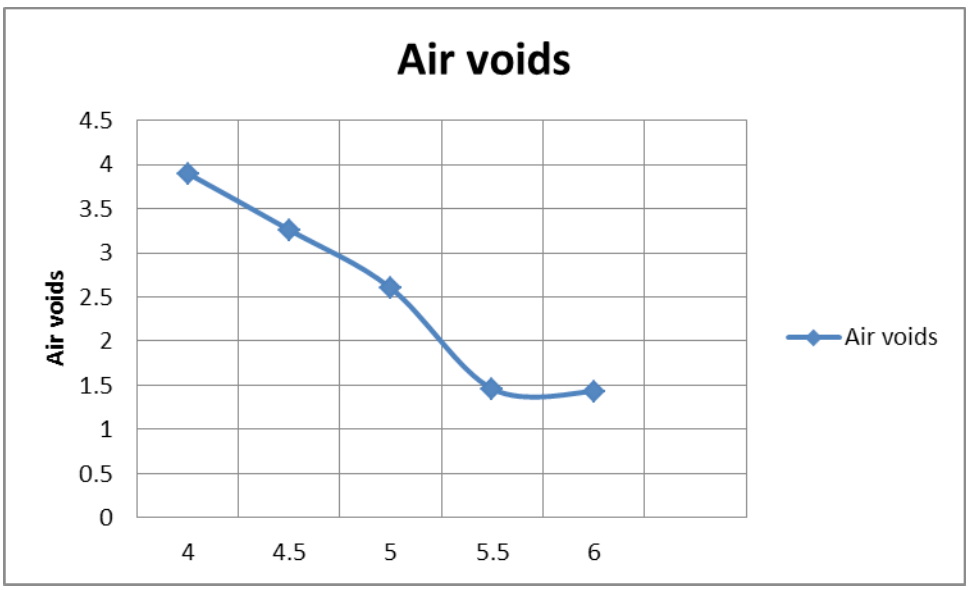
APPENDICE –D sample in oven

First   sample after compaction

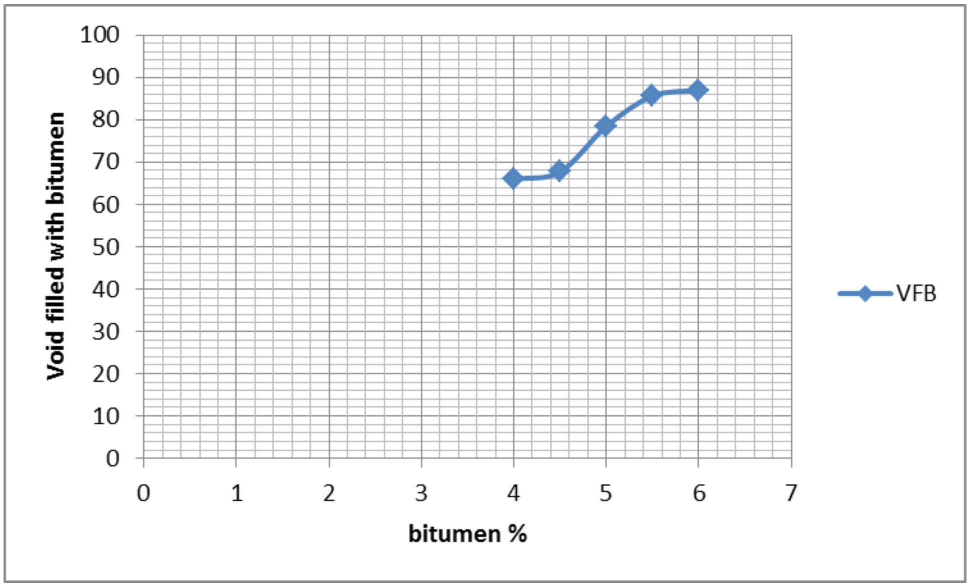
Marshal data: stability values



Air voids curve



Void filled with bitumen (VFA) curve



100
90
80
70
60
50
40
30
20
10
0
Void filled with bitumen
0
1
2
3
4
5
6
7
bitumen %
VFB