JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

CIVIL ENGINEERING DEPARTMENT

HIGH WAY ENGINEERING STREAM

Investigation on The Application of A Byproduct of Awash Melkasa Aluminum Sulfate And Sulfuric Acid (AMASSA) As A Blending Material With Fine Deficient Crushed Stone material For Road Sub-Base Construction

A Research Proposal submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering (Highway Engineering Stream)

By: Abel Tesfaye Tessema

June, 2016

Jimma, Ethiopia

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

CIVIL ENGINEERING DEPARTMENT

HIGH WAY ENGINEERING STREAM

Investigation on The Application of A Byproduct Of Awash Melkasa Aluminum Sulfate And Sulfuric Acid (AMASSA) As A Blending Material With Fine Deficient Crushed Stone For Road Sub-Base Construction

A Research Proposal submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering

(Highway Engineering Stream)

By: Abel Tesfaye Tessema

Advisor: Dr-Ing Fekadu Fufa

Co-Advisor: Eng. Getachew Kebede (MSc)

July, 2015

Jimma, Ethiopia

DECLARATION

This research is my original work and has not been presented for degree in any other University

Abel Tesfaye	**________________**	**__________/____/_____**
Name	**signature**	**date**

This research has been submitted for examination with my approval as a university supervisor

Dr-Ing Fekadu Fufa	**________________**	**__________/____/_____**
Advisor	**signature**	**date**
Engr. Getachew Kebede (MSc)	**________________**	**__________/____/_____**
Co-Advisor	**signature**	**date**

Acknowledgement

First and most, I would like to thank 'Almighty God', who made it possible, not only for enabling me to finish this thesis successfully, but also for his protection and favor in my entire life.

I also acknowledge Jimma University and Ethiopian Road Authority which opened the opportunity for me to study Highway Engineering in JiT. The ERA Jimma district also accepted and helped me during the data collection process of this paper. I would like to say thank you.

Finally would like to express my sincere thanks to my advisor Dr-Ing Fekadu Fufa and my co-Advisor Eng. Getachew Kebede for their invaluable guidance and encouragements.

Abstract

These days, large amount of wastes are generated due to human activities causing unnecessary expenses and requiring large areas for stockpiling. Awash Melkasa Aluminum sulfate and sulfuric acid factory (AMASSA) located at Awash Melkasa in the Main Ethiopian Rift valley region in Oromia Regional State, generates huge stocks of solid wastes. These solid wastes are stockpiled in the compound of the factory. Recycling of wastes in the construction activities has recently harnessed the researchers' attention since it reduces the cost of construction and alleviates environmental pollution problems. Therefore, the aim of this study is to investigate the applicability of the byproducts of AMASSA as blending material for fine deficient crushed stone used as a sub-base materials. The engineering properties of the byproduct and the blending of the byproduct with the fine deficient crushed stone were examined under laboratory set ups. ERA adopted AASHTO standard experimental procedures employed to determine particle size distribution, moisture content, specific gravity, Atterberg limit test, maximum dry density, and optimum moisture content, California bearing ratio, organic content, Loss Angeles abrasion test and Flakiness index were investigated.

The LL and PI of the byproduct material were respectively 74.9 and 12.9. In addition, the particle size distribution analysis results shows that the byproduct materials of AMASSA passed 100% through the 75 µm sieve openings. According to the AASHTO M145 Soil Classification, the results of the Atterberg limit, LL and PI, as well as the particle size distribution of the byproduct material indicate that the material can be classified as clay group, A-7-5. The CBR of the byproduct was found to be 1.6%, suggesting that the materials cannot be utilized as a sub-grade material as per the ERA Technical Specification. The engineering properties of the fine deficient crushed stone were investigated. Accordingly, the fine deficient crushed stone satisfied the ERA Technical Specification to be used as a sub-base material but the crushed stone did not satisfy the range of the specific limit for particle size distribution. The size distribution of the crushed stone for sieve openings of 10, 2.36, 0.425 and 0.075 mm found to be below the lower limit of the AASHTO T27, indicating that the crushed stone used as sub-base materials in the road construction is deficient in fine particles to meet the ERA Technical Specification. These results suggest the need for blending the crushed stone with fine materials to satisfy the technical requirement. Three different blending percent mass ratios of the byproduct of AMASSA, 3, 6.5 and 10%, were used to improve the crushed stone. Accordingly, 3% blending mass ratio improved the particle size distribution (from not satisfying to full filling the technical specification), CBR (from 83 to 102%), and MDD (2.13 to 2.17 g/cc). Besides, the 6.5% blending ratio also improved the particle size distribution, the CBR (83 to 112%) and MDD (from 2.13 to 2.19 g/cc). However, the 10% mass ratio blending increased the PI of the blend of both the byproduct and the crushed stone. Thus, it this mass percent ratio was not further investigated.

The water content, particle size distribution, Atterberg limit, CBR, MDD and OMC of the 3 and 6.5% mass blending ratio results suggest that the blend of the two materials satisfy the AASHTO Technical Specification, avoiding the deficiency in fine materials of the crushed stone that can be used as sub-base material for road construction. Based on the findings the study, it is recommended that the AMASSA byproduct can be used as a blending material for fine deficient crushed stone used as a sub-base material. However, for practical applicability of the byproduct of the AMASSA, further investigations on the determination of optimum percent mass ratio, reaction of the material with other components of the sub-base materials and field investigation will be required.

KEYWORDS: *AMASSA byproducts, Engineering properties, Fine deficient crushed stone, Sub-base materials*

Table of Contents

List of Tables

List of Figures

List of Equations

Abbreviations

AASHTO	American Association of Highway and Transportation Officials
AMASSA	Awash Melkasa aluminum sulfate and sulfuric acid
ASTM	American Society for Testing and Materials
BS	British Standard
CBR	California Bearing Ratio
ERA	Ethiopia Road Authority
LL	Liquid Limit
LAA	Loss Angeles abrasion
MDD	Maximum Dry Density
NP	Non-Plastic
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
RCA	Recycled Concrete Aggregate
USCS	Unified soil classification system

CHAPTER ONE: Introduction

1.1 Background

The modern world generates large amounts of waste, which imposes significant pressure on landfill facilities and the environment (WorkSafe-Victoria 2006).Waste materials have been defined as any type of material by-product of human and industrial activity that has no lasting value (Tam & Tam, 2006). The increasing quantities and type of waste materials, shortage of landfill spaces and the likely shortfall of premium aggregate materials in the near future imposes pressure and urgency on finding innovative ways of recycling and reusing waste materials. The recycling and subsequent reuse of waste materials will also reduce the demand for virgin natural resources which consequently leads to less energy usage, lower cost and ultimately a more sustainable environment (Disfani et al., 2009a).

The beneficial use of recycled and secondary materials in engineering applications is an important step in moving towards a more sustainable society. Materials that normally are either stockpiled indefinitely or disposed of in landfills can be used in combination or in place of natural aggregates in applications such as highway construction. Some materials, such as blast furnace slag, have reached commodity status and are widely used while other materials, such as submerged arc welding slag, are new to the market and are not widely used. One barrier that prevents the use of some materials is the lack of information regarding their physical and environmental properties. Among a list of barriers States face when dealing with secondary materials, the report identified the largest barrier as the lack of good information to use in evaluating the risks to human health and the environment.

The physical properties of a material may be well documented but information on whether a material will leach contaminants after placement, for example, is not known. Testing protocols involving appropriate laboratory leaching methods for recycled and secondary materials are not well established or used widely. There is a lack of laboratory and field data but also a lack of guidelines that material producers and contractors can use to determine whether a material is safe to use or not. Many of these secondary materials have specific properties that make them unique from natural aggregates. Therefore the guidelines that are used for natural aggregates are not always appropriate for these materials. This research would be addresses these issues with regard to the beneficial use of underutilized a byproduct of Awash Melkasa Aluminum sulfate and sulfuric acid.

1.2 Statement of the Problem

Conservation and reuse of resources is a necessity in achieving sustainability across the globe. In recent years, Construction and Demolition (C&D) materials such as concrete, excavation stone (basalt), brick including solid wastes from industries make up a considerable proportion of the waste materials present in landfills around the world (Farhad Reza, 2013). Ethiopia is one of the developing countries that have faced those problem especially solid wastes. Awash Melkasa Aluminum sulfate and sulfuric acid factory is one of the biggest chemical factories in Ethiopia that produce huge amount of solid waste. Blending fine deficient crushed stone sub base materials with industrial byproduct reduces the demand for landfill sites and improves quality of the fine deficient crushed stone to be as a road sub-base material. Therefore this research was conducted to show the possibility of using AMASSA byproduct to be used as a blending material for fine deficient crushed stone material for road sub-base construction.

1.3 Research Questions

- What are the engineering properties of a byproduct of Aluminum sulfate and sulfuric acid?
- What are the engineering properties of fine deficient crushed stone sub-base material?
- What are the engineering properties of fine deficient crushed stone sub-base material blended with a byproduct of Aluminum sulfate and sulfuric acid?
- How to determine the mix ratio of blending and how to evaluate the blended materials accordance with ERA requirements?

1.4 Objectives

1.4.1 General objective

The main objective of this study is to investigate the Application of a Byproduct of Awash Melkasa Aluminum Sulfate and Sulfuric Acid (AMASSA) As a Blending Material with Fine Deficient Crushed Stone for Road Sub-Base Construction

1.4.2 Specific objectives

- To identify the engineering properties of a byproduct of Aluminum sulfate and sulfuric acid.
- To identify the engineering properties of fine deficiency crushed stone sub-base material.
- To examine the engineering properties of the blends fine deficiency crushed stone sub-base material with a byproduct of Aluminum sulfate and sulfuric acid.
- To determine the mix ratio of blending and evaluate the blended materials as a sub-base accordance with ERA requirements.

1.5 Significance of the study

The output of this research is significant for the following; to investigate the possibility of a byproduct of AMASSA as a blending material beneficial use as aggregates for sub-base courses in road construction. This helps to conserve natural stone aggregate and also utilize a byproduct of AMASSA instead of dumping it as waste in a landfill.

1.6 Scope of the study

The scope of the study of this research was laboratory examination of the physical and mechanical properties of the AMASSA byproduct, the fine deficient crushed stone sub-base material and the blending of the first two.

CHAPTER TWO: Literature Review

2.1 Background

The performance of a pavement reflects the proper functioning of the consecutive component layers of a given pavement. The design period, life of the pavement, durability and maintenance cost can be explained by the selection of materials and their characterization. The major component layers are Sub-base, Base courses and their functions are directly reflects the function of Sub-grades (Satyanarayana et al. 2013).

Earlier natural soils, sands, gravel material and Morrum can be frequently used as sub-base materials. The presence of plastic fines and their sticky characteristics hampered the performance of the pavements due to its imbibition of moistures and yields continuous plastic strains. To avoid these component layers, reduce thrust on subgrade and to improve the drainage performance of the sub-base course and durability of the pavement as a whole alternative materials like crusher dust, fly ash, pond ash etc., can be studied. In this an attempt is made for the utilization of mechanically stabilized crushed stone and crusher dust mixes as sub-base and base courses (Satyanarayana et al. 2013).

Besides these products different solid waste particles from industry can be used as sub-base material. Out of such products from industry a byproduct of AMASSA's the one available in our country Ethiopia. To apply such materials as for the construction of pavement structure their engineering properties and method of application has to be developed.

2.2 Solid waste/byproduct

Solid Waste materials have been defined as any type of material by-product of human and industrial activity that has no lasting value (Tam & Tam, 2006). The escalating quantities and type of waste materials, shortage of landfill spaces and the likely shortfall of premium aggregate materials in the near future imposes pressure and urgency on finding innovative ways of recycling and reusing waste materials. The recycling and subsequent reuse of waste materials will also reduce the demand for virgin natural resources which consequently leads to less energy usage, lower cost and ultimately a more sustainable environment (Disfani et al., 2009a).

Such solid waste/byproducts exists in different forms and can be obtained from different sources. And each of them were used in different ways as road construction materials. Some of this includes crushed aggregates and crusher dust mixes in flexible pavements from the production sites or quarry sites as (Satyanarayana et al. 2013), steel slag as a road construction material (Mohd. RosliHainin et al. 2015) which is generated from different steel industries and specifications were developed by countries for Supply of recycled materials for pavements, earthworks and drainage (IPWEA (NSW), 2010).

This guide (IPWEA (NSW), 2010) is to be used for the selection of recycled materials, primarily crushed concrete, brick and reclaimed asphalt blends for use in local road and pedestrian pavements, minor supporting earthworks and as backfill material for drainage lines and drainage structures. Its use is limited to applications having maximum nominal particle sizes of up to 100mm. The use of other recycled materials such as crushed glass fines and flash as well as blends of recycled and virgin materials is provided for under the guide.

These materials are not the only used materials for constructions roads. In different countries different materials were used based on their availability. In usage of the materials their suitability to the local conditions by analyzing their properties. For instance, in using steel slag as a road construction material their production and utilization of steel slag, chemical and mineral composition of steel slag which includes *affinity of steel slag with binder*, physical and mechanical properties of steel slag which includes *specific gravity, grain-size distribution, compaction characteristics, shear resistance, thermal properties* were considered. (Mohd. RosliHainin et al. 2015)

The other waste material used for road construction is recycled glass. Recycled glass exhibits geotechnical properties similar to natural aggregate materials especially to those of mixtures of gravel and sand. Recycled glass has many potential benefits in terms of geotechnical and drainage applications (Landris, 2007, Ooi et al., 2008, Wartman et al., 2004).

Recycled glass particles are generally angular shaped and contain some flat and elongated particles with a flakiness index of up to 95% reported for some recycled glass resources (Disfani et al., 2011). The geotechnical and geo-environmental evaluation of recycled glass in road embankment applications has been reported in recent years (Disfani et al., 2011, Disfani et al., 2012, Grubb et al. 2006a, Grubb et al., 2006b, Wartman et al., 2004).

RCA has been investigated as pavement base and backfill materials (Paul et al., 1996). RCA can be effectively used in pavement base and sub-base as it is environmentally friendly and desirable high strength construction material (Park, 2003). RCA has been recently evaluated in the laboratory for pavement base and sub-base applications by several authors whom have reported that it was a suitable material for pavement base and sub-base applications (Azam et al., 2012, Gabr et al., 2012). Gomez-Soberon (2002) reported that RCA would provide better drainage in base and sub-base than a natural aggregate as it possesses higher values of void ratio, porosity and hydraulic conductivity than a natural aggregate.

Waste rock is excavated rock from construction sites for residential sub divisional development (Arulrajah et al., 2012a). Usually, this rock has been disposed into landfills as a waste. However, due to its hardness and durability, this rock has been crushed and used in pavement base/sub-base as a replacement material for high quality aggregates in various countries. (Akbulut et al., 2007, Nunes et al., 1996, Papagiannakis et al., 2007, Rodgers et al., 2009, Saride et al., 2010, Tao etal., 2010).

For the case of this research, AMASSA solid waste is the material that is considered as a blending material. AMASSA byproduct, generated during the manufacture of aluminum sulfate using kaolin and sulfuric acid. The byproduct directly discarded contains about 52% of solid. The chemical compositions of this industrial by product are given in Table 1. The collected waste residues were sundried for one day and ground to fine powder using mortar and the resulting material is considered as untreated media. The chemical composition of the waste material indicates the absence of any hazardous.

Table 1: Percentage composition of the chemical constituents in waste residue (Haimanot, 2014)

Chemical Composition	Percent (Wt. %)	Chemical Composition	Percent (Wt. %)
Quartz (SiO_2)	40	K_2SO_4	0.005
Kaolin	8.883	$Al_2(SO_4)_3$	1.778
$Al(OH)_3$	0.878	$CaSO_4$	0.194
$Fe_2(SO_4)_3$	0.023	FeO_3	0.001
$MgSO_4$	0.008	Na_2SO_4	0.007

2.3 Material Requirements for Sub-Base

Gravel material to be used for sub-base shall be obtained from approved sources in borrow areas, cuttings or existing pavement layers and shall conform to requirements specified herein. The aggregate used for crushed stone sub-base shall be derived from a parent rock that is hard, sound, durable, and un-weathered and obtained from an approved quarry or clean sound boulders. Its hall contain no deleterious material such as decomposed rock, clay, shale, or mica. Single stage crushing will not be allowed and the crusher installation shall be capable of producing material complying with the specified requirements. If the nature of the parent rock is such that despite every effort made, the material remains deficient in the finer fractions, the Engineer may allow the addition of approved soil fines, crusher fines or sand in controlled quantities not exceeding 15% by mass of the aggregate. Fines shall be introduced at the crushing plant. (ERA, 2013)

2.4 Road base and sub base

Where possible, naturally occurring unprocessed materials should be selected for sub-base and road base in paved low volume roads. However, under certain circumstances, mechanical treatments may be required to improve the quality to the required standard. This often requires the use of special equipment and processing plants that are relatively immobile or static. For this reason, the borrow pits for road base and sub-base materials are usually spaced widely. In current practices, distances between these pits of about 50km are not unusual. Main sources of sub-base and base materials are rocky hillsides and cliffs, high steep hills, and river banks. In Ethiopia, sub-base materials have also been extracted from cinder cones and lateritic deposits. Sub-base materials are expected to meet requirements related maximum particle size, grading, plasticity, and CBR (ERA, 2011).

The sub-base is an important load spreading layer in the completed pavement. It enables traffic stresses to be reduced to acceptable levels in the subgrade, it acts as a working platform for the construction of the upper pavement layers and it acts as a separation layer between subgrade and base course. Under special circumstances, it may also act as a filter or as a drainage layer. In wet climatic conditions, the most stringent requirements are dictated by the need to support construction traffic and paving equipment. In these circumstances, the sub-base material needs to be more tightly specified. In dry climatic conditions, in areas of good drainage, and where the road surface remains well sealed, unsaturated moisture conditions prevail and sub-base specifications may be relaxed. The selection of sub-base materials will therefore depend on the design function of the layer and the anticipated moisture regime, both in service and at construction (ERA, 2002).

2.5 Blending

Blending involves the mixing of materials that have different properties (typically particle size distribution and/or plasticity) to form a material with characteristics that improve upon the limitations of the source materials. Improving strength or plasticity is usually the primary reason for implementing mechanical stabilization. In most instances, blending will involve adding coarse aggregates to the finer in situ material.

2.6 Stabilization in road pavements

There are many different reasons for using stabilization, ranging from lack of good quality materials to a desire to reduce aggregate usage for environmental reasons. Ultimately the main reason for using stabilization will usually be cost savings. The engineer is trying to build a problem-free pavement that will last for its intended design life for the most economic price. The cost savings associated with stabilization can take many forms including reduced construction costs, reduced maintenance costs throughout the life of the pavement or an extension of the normal pavement life.

Not all materials can be successfully stabilized, for example if cement is used as the stabilizer then a sandy soil is much more likely to yield satisfactory results than a soft clay (Watson, 1994). The material to be stabilized must be tested to ensure that it is compatible with the intended stabilizer – the subject of testing will be discussed later in this report. It is also recommended from experience that layers which are less than150mm thick should not be stabilized (Lay, 1986/88).

A stabilized, and therefore stiffer, sub-base provides greater load spreading ability and hence reduces stresses imposed on the subgrade. When stabilized the sub-base provides much of the structural rigidity in the pavement, and also assists during the compaction of the upper granular layers and hence increases their ability to withstand deformation.

2.6.1 The role of a stabilized sub-base in a flexible pavement

If the sub-base is stabilized, reflection cracking in an asphalt surface layer can be minimized by having an unbound granular road base. This unbound road base provides not only a large proportion of the structural load spreading but also assists in delaying or preventing reflection cracking from the shrinkage and movement of the stabilized layer. The granular road base is subjected to relatively high traffic stresses and crushed aggregate is often used to withstand attrition and to assist in achieving a high value of elastic modulus, limiting the horizontal tensile strains at the bottom of the bituminous surfacing.

The use of a stabilized sub-base with a granular base is often referred to as an 'upside-down pavement' (Lay 1986). It is reported (LCPC, 1997) that a typical mode of deterioration for this type of pavement, based on experience from France, is slight rutting attributed to the unbound granular layer and eventually fine transverse cracking which occurs after much trafficking.

2.6.2 The role of a stabilized sub-base in a rigid pavement

For a concrete pavement, the term 'sub-base' refers to the layer immediately below the concrete slab. In a concrete road, the high elastic modulus of the concrete layer causes most of the traffic-induced stresses to be taken in the concrete layer in the form offending stresses.

According to O'Flaherty (1994), there is a common misunderstanding about the main function of the sub-base beneath a concrete slab. He states that the main function of the sub-base is to ensure uniform support to the concrete, counteracting the effect of unsatisfactory subgrade support, rather than increasing the structural stability (i.e. Strength) of the pavement.

2.7 Mechanical Stabilization

The most basic form of mechanical stabilization is compaction, which increases the performance of a natural material. The benefits of compaction, however, are well understood and so they will not be discussed further in this report.

Mechanical stabilization of a material is usually achieved by adding a different material in order to improve the grading or decrease the plasticity of the original material. The physical properties of the original material will be changed, but no chemical reaction is involved. For example, a material rich in fines could be added to a material deficient in fines in order to produce a material nearer to an ideal particle size distribution curve. This will allow the level of density achieved by compaction to be increased and hence improve the stability of the material under traffic. The proportion of material added is usually from 10 to 50 per cent.

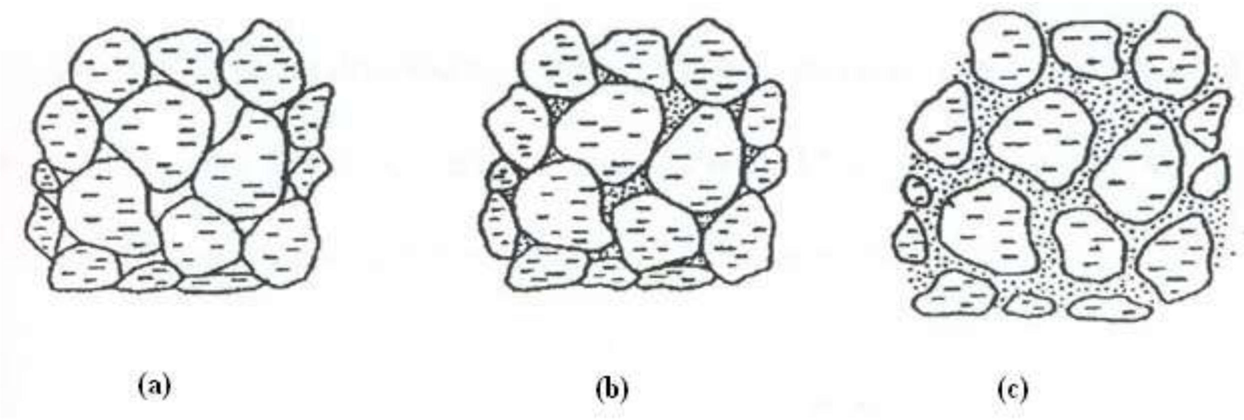
Providing suitable materials are found in the vicinity, mechanical stabilization is usually the most cost-effective process for improving poorly-graded materials. This process is usually used to increase the strength of a poorly-graded granular material up to that of well-graded granular material. The stiffness and strength will generally be lower than that achieved by chemical stabilization and would often be insufficient for heavily trafficked pavements. It may also be necessary to add a stabilizing agent to improve the final properties of the mixed material.

2.8 Engineering Properties

2.8.1 Particle size and gradation

The particular packing arrangement for a material is normally represented by the particle size distribution (gradation) curve based on proportions (by mass) passing successive sieves. A lack of coarse or finer particles would produce an unbalanced gradation or distorted gradation curve resulting in poor mechanical stability and unsatisfactory compaction. Therefore, an improvement in gradation and in the reduction of oversized material will result in more uniform strength development, uniform mixing and compaction. It is preferable to have a gradation with continuously smooth curve from the maximum particle size to the smallest particle size with no excess or lack in certain particle fractions. The gradation depends on the amount of weathering of the material. This means that material close to the surface will most probably be finer graded than material that is retrieved at a greater depth (Witezak, 1975).

An aggregate, with little or no fines content as shown in figure 2.2a, gains stability from grain-to grain contact. An aggregate that contains no fines usually has a relatively low density but is pervious and not frost susceptible. This material is however difficult to handle during construction because of its non-cohesive nature.



Aggregate with no fines | Aggregate with sufficient fine | Aggregate with large amount of fines

Figure 2.2: Physical States of Soil Aggregates Mixture

An aggregate that contains sufficient fines to fill all voids between the aggregate grains will still gain its strength from grain-to-grain contact but has increased shear resistance as shown in figure2.2b. Its density is high and its permeability is low. This material is moderately difficult to compact but is ideal from the standpoint of stability. As shown in figure 2.2c, material that contains a great amount of fines has no grain-to-grain contact and the aggregate merely ‘float’ in the soil. Its density is low; it is practically impervious and it is frost susceptible. In addition, the stability of this type of material is greatly affected by adverse water conditions. Paradoxically the material at times is quite easy to handle during construction and compacts quite readily (Witezak, 1975).

2.8.2 The Los Angeles Abrasion (LAA.)

Abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in HMA must resist crushing, degradation and disintegration in order to produce a high quality HMA. The standard L.A. abrasion test subjects a coarse aggregate sample (retained on the No. 12 (1.70 mm) sieve) to abrasion, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. After being subjected to the rotating drum, the weight of aggregate that is retained on a No.12 (1.70 mm) sieve is subtracted from the original weight to obtain a percentage of the total aggregate weight that has broken down and passed through the No. 12 (1.70 mm) sieve. Therefore, an L.A. abrasion loss value of 40 indicates that 40% of the original sample passed through the No. 12 (1.70 mm) sieve. The standard Los Angeles abrasion test is: AASHTO T 96 or ASTM C 131: Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

2.8.3 California Bearing Ratio (CBR) test

This test method covers the determination of the CBR of pavement sub-grade, sub-base, and base course materials from laboratory compacted specimens. The method uses soil particles that pass 19 mm size and provides CBR value of a material at optimum water content. The specimen shall be soaked prior to penetration. This test simulates the prospective actual condition at the surface of the sub-base. A surcharge is placed on the surface to represent the mass of pavement material above sub-base. The sample is soaked to simulate its weakest condition in the field. Expansion of the sample is measured during soaking to check for potential swelling. This method covers the laboratory determination of the California Bearing Ratio (CBR) of a compacted or undisturbed sample of soil. The principle is to determine the relation between force and penetration when a cylindrical plunger with a standard cross-section area is made to penetrate the soil at a given rate. At certain values of penetration the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio (CBR). According to ERA manual, for the sub-base material the minimum soaked California Bearing Ratio (CBR) shall be 30% when determined in accordance with the requirements of AASHTO T193. The Californian Bearing Ratio (CBR) shall be determined at a density of 95% of the maximum dry density when determined in accordance with the requirements of AASHTO T-180 method D (ERA, 2002).

2.8.4 Atterberg Limits

The liquid limit may be defined as the minimum moisture content at which the soil will flow under the application of a very small shear force. At this moisture content the soil is assumed to behave practically as a liquid. The plasticity limit may be defined in general terms, as the minimum moisture content at which the soil remains in plastic condition. The plastic limit is further described as the lowest moisture content at which the soils can be rolled in to thread of 3.2mm diameter without crumbling. The "Plasticity index" (PI) of a soil is defined as the numerical difference between the liquid and plastic limits. It thus indicates the range of moisture content over which the soil is in a plastic condition.

Plasticity is an important factor in the performance of a gravel wearing course for the following reasons. Material with plasticity that is too low tends to loosen quickly as a result of diminished bonding and the rate of gravel loses is generally very high. Loose material is pushed off into the drains or washed away by run-off or blown away by wind when dry. High gravel lose reduces re-gravelling cycle periods causing high maintenance cost and general whole life costs. High plasticity on the other hand causes the wearing course to be slippery when wet and the material may soften to an extent where the gravel layer may actually deform and fail instantly under traffic. According to ERA specification, all sub-base materials shall have a maximum plasticity index of 6 when determined in accordance with AASHTO T-90 (AACRA, 2003).

2.8.5 Moisture – Density relations by modified proctor test

Practically most soils exhibit a similar relationship between moisture content and density (dry unit weight) when subjected to dynamic compaction. That is, practically the cohesive soils have an optimum moisture content at which the soil attains maximum density under a given compacting effort but the granular soils difficult to define. This fact, which was first stated by R.R. Proctor in a series of articles published in Engineering News-Record in 1933, forms the basis for modern construction process commonly used in the formation of highway sub-grades, bases, embankments, and earthen dams. In laboratory, dynamic compaction is achieved by use of a freely falling weight on confined soil mass; in the field, similar compaction is secured through the use of rollers or vibratory compactors applied to relatively thin layers of soil during construction process. Compaction is a process by means of which the soil can be densified. In soils there is some amount of air and water besides solid grains. Theoretically the density of soil can be increased by:

· By reducing the space occupied by the air.

· By elastic compression of soil grains.

Compaction takes place due to expulsion of air from the voids of the soil mass by applying any mechanical means (Sinha, 1998). It is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the soil. The dry density, which can be achieved, depends on the degree of compaction applied and on the amount of water present in the soil. For a given degree of compaction of a given cohesive soil there is an optimum moisture content at which the dry density obtained reaches a maximum value. For cohesion less soils optimum moisture content might be difficult to define**.** The determination of the relationship between water content and density of soils is used in determining the compaction of the material. The purpose of compaction is to arrange the particles in such a way as to achieve the highest possible density for the layer with minimum voids. By achieving high densities, not only is the shear strength and elastic modules improved but also the ingress of water is reduced or eliminated. In this research, a heavily trafficked asphalt road was considered hence the modified proctor test is used. The Ethiopia Road Authority recommends using AASHTO T-180 method D. In this test, a specimen is prepared by compacting soil in 152.4 mm mold in five approximately equal layers to give a total compacted depth of about 127 mm, each layer being compacted by 56 uniformly distributed blows from the rammer.

The crushed stone material has little fine-grained soil content and gains its stability from grain-to-grain contact; consequently it usually has relatively low density. Adding fine-grained soil to the crushed stone material still gains its strength from grain-to-grain contact and leads to the increment of density up to an optimum point. The crushed stone material that contains optimum amount of fine-grained soil fills all the voids. This results in high density. Beyond this optimum fine-grained soil grain-to-grain contact gradually decreases leading to the decrement of density.

2.8.6 Water absorption

It is used to determine the amount of water absorbed under specified conditions. Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environments. (ASTM D570).

2.8.7 Organic content.

This test is performed to determine the organic content of soils. The organic content is the ratio, expressed as a percentage, of the mass of organic matter in a given mass of soil to the mass of the dry soil solids. (ASTM D 2974 – Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Organic Soil)

CHAPTER THREE: METHODOLOGY

3.1 Sampling Technique

Samples of the solid residue from the factory were collected with the relevant ERA sampling procedure (ERA, 2002). Seven separate samples were collected in different clean plastic bags from seven batches of the solid waste generated and then thoroughly mixed to have a composite sample.

Figure 1: Sampling Technique in the laboratory (Date: 01/06/2016)

3.2 Study Design

The study design for this research was the findings of laboratory evaluation on the use of a byproduct of AMASSA blends as unbound road base/sub-base materials.

Figure 2: Blending of Crushed stone sub-base material with AMASSA byproduct (Date: 28/05/2016)

3.3 Study Variable

Independent variable: The independent variables for this research were as follows; particle size distribution, modified Proctor compaction, water content, California bearing ratio (CBR), Los Angeles abrasion, organic content, Atterberg limit and Flakiness Index

Dependent variable: Property of crushed stone material, a byproduct of AMASSA and blending material.

3.4 Data Collection Process

Two types of aggregates were used in this study. The first one was a byproduct, generated during the manufacture of aluminum sulfate and sulfuric acid, and was collected from Awash Melkasa Aluminum Sulfate and Sulfuric Acid Factory which is located at the central part of the Ethiopian Rift Valley Region. The second type, fine deficient crushed stone sub-base material was taken from existing crusher sites, Limmu Kosa District, Jimma Zone

Figure 3: Material Collection (Date: 18/09/2015 GC)

3.5 Data Analysis

The study was analyzed in relation to the theoretical propositions. In order to address the objectives and to answer the given research questions, the study was analyzed quantitatively. The properties of crushed stone material was determined in the laboratory in terms of particle size distribution, modified Proctor compaction, water content, California bearing ratio (CBR), Los Angeles abrasion, organic content, Attar barge limit and then it was evaluated according to ERA manual specification and similarly the engineering properties of the byproduct and the blends were done. The ratio of blending of a byproduct with a fine deficient crushed sub base material was determined that was attain the requirements of a sub base material under ERA manual specification. The data generated from the analysis were tabulated and described using tables, graphs and percentage.

3.6 Laboratory Test Based Data Analysis

In this study, the laboratory tests were conducted according to ERA standards and material sampling also was done as per ERA's specifications and tests were performed in Ethiopian Road Authority office at Jimma district laboratory center .The tests were done to determine the engineering properties of a byproduct of AMASSA, the fine deficient crushed stone sub base and the blended of those materials. Tests conducted on the byproduct of AMASSA materials were, particle size distribution, water content, specific gravity, Atterberg limit tests (plastic limit (PL), liquid limit (LI), plastic index (PI), soil classification, maximum dry density(MDD) and optimum moisture content (OMC) (compaction tests), California Bearing Ration (CBR), and organic content. The tests that carried out for fine deficiency crushed stone sub base and the blends were sieve analysis, water content, Atterberg limit tests (plastic limit (PL), liquid limit (LI), plastic index (PI), maximum dry density(MDD) and optimum moisture content (OMC) (compaction tests), California Bearing Ration (CBR), Los Angeles abrasion (LAA) and Flakiness index.

3.6.1 Particle size distribution

This was done to determine the percentage particle size distribution of a given sample of fine deficiency crushed stone sub base, a byproduct of AMASSA and blends. Dry and Wet Sieving analysis were performed on a fine deficiency crushed stone sub base, a byproduct of AMASSA and the blends of the samples of the materials.

Sieve analysis was carried out to determine the distribution of material sizes. The fine deficient crushed stone and the blends were sieved using a series of sieve sizes placed at a descending order (50mm,37.5mm,20mm,10mm,5mm, 2.36, 0.425mm, 0.075mm and a pan) and the byproduct of AMASSA was sieved through 0.075mm sieve by wet sieving. The material was allowed to pass through these sieves using a hand shake. The material retained on each sieve was recorded and then the mass and percentage of material retained as well as percentage of passing material were calculated.

Figure 4: Sieve Analysis (Date: 11/05/2016)

3.6.2 Moisture Content Determination

This test was performed to determine the water (moisture) content of a byproduct of AMASSA, fine deficiency crushed stone sub base and blends separately for each material. To conduct moisture content testes the equipment such as Drying oven, Balance, Moisture can, Gloves, Spatula were used.

For determination of water content of each material that stated in the above the first procedure was recording the mass of an empty, clean, and dry moisture can with its lid (Mc) and the placing moist soil in the moisture can and secure the lid and its mass was recorded. After that the moisture can (containing the moist soil) was placed in the drying oven that was set at 105 °C at least 16hrs in the oven. It was allowed to cool in room temperature and the mass of the moisture can and lid (containing the dry soil) (M_{CDS}) was determined. Finally, the mass of soil solid, pore water and water content were determined and recorded using the formula stated below:

$M_s = M_{CDS} - M_{SC}$ $MS = MCDS - MSD$ where MS

$M_W = M_{CMS} - M_{CDS}$

Water content (w) = (Mw/ Ms)*100

3.6.3 Specific gravity

The specific gravity of byproduct of AMASSA was carried out using pycnometer during laboratory test for the study.100g of mass of oven dried byproduct of AMASSA was socked for 16hrs in pycnometer that filled with water by 2/3 volume of pycnometer. The socked byproduct of AMASSA was boiled at 200 ^{o}C for 2hrs in order to entrap the air from the material and then it was cooled to room temperature and pycnometer was filled with water again totally while temperature of it was measured using thermometer. Finally, mass of empty pycnometer, mass of pycnometer with socked and boiled byproduct of ASSA filled with water and mass of pycnometer filled with water.

$$Specific\ Gravity, Gs = \frac{W0}{W0+(WA-WB)}$$

Equation 1: Specific Gravity

Where, W_O isweight of sample of oven dried soil g= W_{PS}- W_P; WA is weight of pycnometer filled with water; $W_B$is weight of pycnometer filled with water and soil.

Figure 5: Specific Gravity Test (Date: 02/10/2015)

3.6.4 Atterberg limit tests

This lab was performed to determine the plastic and liquid limits of a fine grained soil. Liquid limit was tested using AASHTO T-90. It was done using fines from sieve analysis test (material below 0.425mm). The fines were mixed with distilled water to form a thoroughly mixed stiff consistency. The material was then laid and levelled into a bowl of a liquid limit device. Grooving tool was used to divide the material at the center thus making two equal halves. The liquid limit device was tapped at a rate of two taps per second. The material was tapped until it was touching one another along a distance of 13 mm (1/2 in.). The liquid limit sample was taken around the touching. The process was repeated three times whereby the first samples was taken between 25 to 35 taps, second one after 20 to 30 and the third after 15 to 25 taps. The samples were oven dried for a period of not less than 16 hours at a temperature of 110^{0}C. The moisture content was calculated by dividing the mass of oven dried material with mass of wet material. The graph of moisture content versus number of taps was drawn as a straight line. The corresponding moisture content at 25 taps was taken as the liquid limit of the material.

Figure 6: Photograph of liquid limit sample mixing (Date: 12/05/2016)

Figure 7: Photograph of liquid limit test apparatus (Date: 12/05/2016)

Plastic limit and plastic index (PI) test was done according to AASHTO T-90. The material was rubbed on the palm of hands thus making strips of material. This was done to reduce moisture content up until material breaks on its own, the thread shall be deformed so that its diameter reaches 3.2 mm (1/8inch), taking no more than two minutes and was regarded as limit for material plasticity. Samples of broken strips material were collected and oven dried for at least 16 hours at a temperature of 110^0C. Plastic limit was calculated as a percentage of the mass of oven dried material divided by the mass of wet material. The average of three results was taken as the plastic limit.

PI is the difference between liquid limit and plastic limit and was calculated using the following formula:

PI = LL – PL

PI – Plastic Index

LL – Liquid limit

3.6.5 MDD and OMC:

The 2.5kg, 6kg and 6kg samples prepared for a byproduct of AMASSA, a fine deficiency crushed stone sub base and the blends respectively that were used to test MDD and OMC according to AASHTO T 180. These tests were done to determine the material behavior when moisture is added in relation to density and was prepared and compacted according modified AASHTO compaction. Four different percentages of water were added into the materials such that MDD was obtained. The material was well mixed and compacted in 5 layers per mold. Each layer was compacted with 25 blows for a byproduct of AMASSA and 56 blows were done for a fine deficiency crushed stone sub base and for the blends. Upon compaction the mass of compacted material was taken and was divided with volume of mold in order to get dry density. Samples of moisture content were taken on every percentage of water mixed and were oven dried for not less than 16 hours. The difference between the mass of wet material and oven dried material was taken as moisture content in percentage. The results of density and moisture content were used to plot a graph of dry density versus moisture content. This graph was used to determine the MDD and OMC of the material.

Figure 8: Maximum Dry Density Test (Date: 3/11/2015)

Figure 9: Optimum Moisture Content Test (Date: 26/05/2016)

3.6.6 CBR

In this study, CBR test was determined according to AASHTO T 193. This test was done to determine the load that the material can carry in kilonewtons per square meter (kN/m2). Three samples of six kg each were prepared for the test. The optimum moisture determined during the MDD vs. OMC test was used for compaction. First sample was compacted using modified AASHTO method (5 layers and 65 blows per layer) and then the second sample was compacted (5 layers and 30 blows per layer). In the next, third sample was compacted (5 layers and 10 blows per layer).The three compacted molds were placed on a perforated base plate, and a surcharge of 4.356kg was placed on top of a sample. The samples were then placed into the soaking bath container. The samples were allowed to rest on top of elevated surface to allow water to penetrate through the perforated base plate without disturbance. Tripod dial gauge was used to take a reading before soaking. The bath was then filled with water till it was 12mm above the mold. The material was then soaked for 4 days and swell readings were taken during the process. On the fourth day the molds were taken out for penetration .A Penetration rate of 1.27mm per minute was used and load readings taken on every 0.635mm penetration. The graph of depth penetration versus load was drawn. The readings at 2.54mm and 5.08mm were compared to California standard values of each penetration depth.

Figure 10: CBR Test (Date: 02/06/2016 and 06/06/2016)

3.6.7 Los- Angeles abrasion test (LAA)

Los- Angeles abrasion test was conducted to determine the hardness of aggregates used in pavement construction of fine deficiency crushed stone sub base according to AASHTO T 96. Los Angeles machine and sieves were utilized for the test. Clean oven dried sample was sieved through 1.8 mm sieve and weighed. The specimen was placed in the cylinder machine and then a rotation of 500 revolutions at a speed of 28 to 30 revolutions per minute had been done. After the desired number of revolutions performed, the material discharged and graded through 1.8 mm size sieve. The material that was coarser than 1.7 mm size had been washed and dried in an oven and weighed. The difference between the original and final weights of the sample was expressed as a percentage of the total weight of the sample and recorded as the percentage wear.

3.6.8 Flakiness Index

Flakiness index was determined according to BS812, Part 105. This test was done to determine the amount of flaky aggregates within the sample. In order to perform the test, the quantity of the aggregate taken to be tested was reduced to the sample complying with and this sample was washed, oven dried, cooled and weighed to get substantially constant weight. Then this sample was sieved as in the. All the aggregates retained on the 63mm sieve and passing the 6.3mm sieve were discarded and each of the individual size-fraction retained on the sieves weighed and stored in trays marked with their respective sizes. From the sums of masses of the fraction in the trays (M_1), the individual percentage on each of the various sieves were calculated. Any fraction whose mass is 5% or less of the mass M_1 were discarded and the remaining mass is then recorded (M_2). After all the above steps each of the aggregate particles were passed through their corresponding slot in the thickness gauge and finally all the particles passing each of the gauges were combined and weighed (M_3).

The mass passing through the slot was recorded. Flakiness index was calculated using the following expression:

Flakiness index = (total mass of aggregates passing slots/ mass of test sample) * 100

3.6.9 Organic content

This test was conducted so as to determine the organic content of the byproduct of AMASSA according to the ASTM D 2974 – Standard Test Methods. Muffle furnace, Balance, Porcelain dish, Spatula, Tongs are the equipment that were used to conduct the test. The first step that was done for testing the organic content of the material in the laboratory is measuring and recording the mass of the empty, clean and dry Porcelain dish (M_p). Then the oven-dried test specimen from the moisture content experiment in the porcelain dish were placed and the mass of the dish and the specimen (M_{PDS}) were determined and recorded. After this the dish was placed in a muffle furnace and the temperature in the furnace was gradually increased to 440 ^oC and it was left in the furnace overnight. Finally the porcelain dish containing the ash was removed from the Furnas and weighed after being cooled to room temperature (M_{PA}). The organic content of the byproduct was calculated using the following formula the (ASTM D 2974)

$$\text{Organic Content} = \frac{\text{Mass of organic matter(M0)}}{\text{Mass of dry soil (Md)}} \times 100$$

Equation 2: Organic Content

CHAPTER FOUR: RESULTS AND DISCUSSIONS

According to the laboratory tests conducted and their respective procedures, several tests had been conducted over the AMASSA by product, the fine deficient Crushed stone sub-base material and the blended material of the byproduct and the fine deficient crushed stone Sub-base material. The tests made on the AMASSA byproduct are Particle size distribution, Moisture content, Specific gravity, Atterberg Limit Test, Maximum Dry Density, Optimum Moisture Content, California Bearing Ratio (CBR) and Organic Content. In the meantime the soil classification of the byproduct is also made based on its particle size distribution and Atterberg Limit according to the AASHTO Standard M-145. The second group of tests conducted are those tests which are conducted on the fine deficient Crushed Stone Sub-base material. These are Particle Size Distribution, Moisture Content, Atterberg Limit Test, Maximum Dry Density and Optimum Moisture Content, Californian Bearing Ratio, Loss Angeles Abrasion Test and Flakiness Index. The final group of tests conducted are those that are made on the material which is the mix of the byproduct and the fine deficient Crushed Stone Sub-base discussed above. These are; Particle Size Distribution, Atterberg Limit, Maximum Dry Density, Optimum Moisture Content and California Bearing Ratio. Therefor the test results of the above three group of laboratory tests and their respective discussions are presented in the following three sub topics.

4.1 AMASSA Byproduct

4.1.1 Particle Size Distribution

The particle size distribution of the byproduct is conducted by a sieve analysis according to AASHTO T-27. The particle size distribution analysis result is given in Table 2. The byproducts of AMASSA material passed through 75 µm (No. 200) sieve size, showing that the byproducts was finer than75 µm. This indicates that the material particle size distribution can be used as a blending material for fine deficient crushed stone sub-base materials.

Table 2: Results of sieve analysis of the byproduct of *AMASSA*

sieve size, mm.	% passing
4.75mm	100
2.36mm	100
0.425mm	100
0.075mm	100

4.1.2 Moisture Content and Specific Gravity

Laboratory test results showed that the average of the duplicate measurement of the moisture content & specific gravity of the AMASSA byproduct are 9.7 % and 2.385 respectively. Therefore, the AMASSA byproduct has high water content because of its high porosity and it is a lightweight material.

4.1.3 Atterberg Limit

The results for LL was 74.9 while the average of duplicate measurement of PL was 62 and the difference between the two indicated that the PI of the material was 12.9 (*Appendix D*).The material had high PI which was meeting clayey material specifications.

4.1.4 Soil Classification

Soil classification of the byproduct was assessed after the laboratory test results of its gradation and Atterberglimits that is shown in the Table 2 and *Appendix D*. The result of particle size distribution analysis shows that 100 % of the material tested passed through No. 200 sieveand its LL as well as PI were 74.9 and 12.9, respectively. These results show that material can be classified as clay group, A-7-5 according to AASHTO M-145 standard (AASHTO, 1993).

4.1.5 MDD and OMC and CBR

The results showed that the material had MDD of 0.889 g/cc and OMC of 63.7 %. The results showed that the material had a low MDD and high OMC.

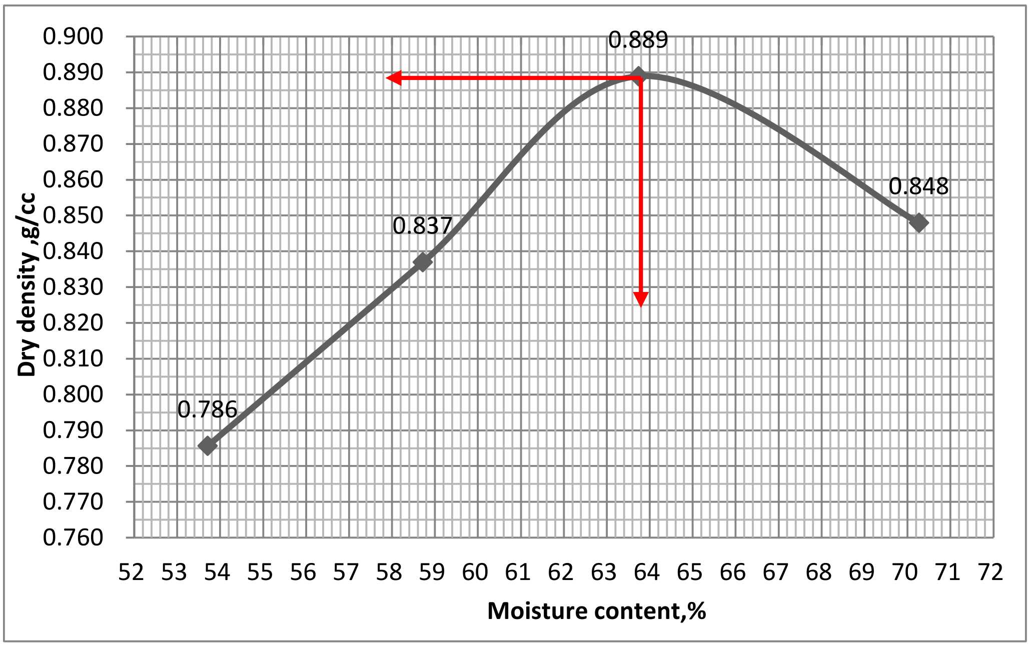


Figure 11: MDD vs. OMC of the byproduct of AMASSA

The result of CBR test done according to AASHTO T193 are as shown in Figure 12. The results showed that the CBR of the byproduct of AMASSA was 1.6%. Thus, the material was not meeting even the subgrade material strength specifications.

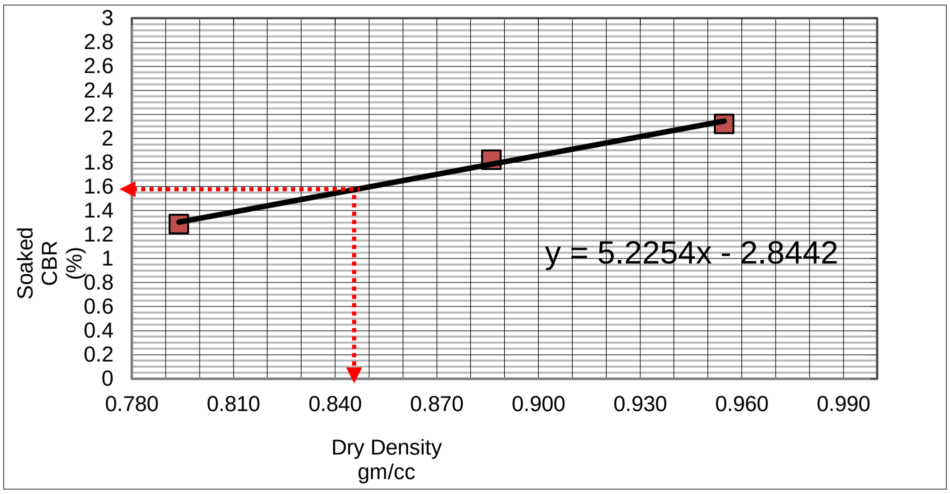


Figure 12: CBR of Byproduct of AMASSA

4.1.6 Organic content

The laboratory based experiment was done on a byproduct according to ASTM D2974 (2007) to determine the organic content of the byproduct of AMASSA and the average duplicate measurement were 0.90 %. According to this manual soils with organic content less than 5 % are acceptable to be suitable road making materials.

4.2 Engineering Properties of Fine Deficient Crushed Stone Sub-base

4.2.1 Particle size distribution

The particle size distribution of the byproduct is conducted by a sieve analysis according to AASHTO T-27. The average of the duplicate measurement of the results obtained by this test is presented in Table 3

Table 3: Test results of sieve analysis of fine deficient crushed stone sub-base

Sieve size (mm)	Weight retained (partial)	% retained	% passing	Specific Limit	
50	0	0	100	100	100
37.5	0.0	0.0	100.0	100	100
20	5716.0	38.9	61.1	60	80
10	3191.5	21.7	39.5	40	60
5	1941.9	13.2	26.3	25	40
2.36	1802.1	12.2	14.0	15	30
0.425	1111.3	7.6	6.4	7	19
0.075	643.6	4.4	2.1	5	12
Pan	0.0				
Dry weight after washing	14406.3	100.0			

The result showed that the grading does not satisfy the requirement of AASHTO T-27 as the only sieve sizes which are in the specific limit for graduation are Sieves with the size of 50mm, 37.5mm, 20mm and 5mm. For the rest of the sieve sizes the material doesn’t satisfy the specific limit for graduation. From the test result, it is shown that the material comprises of coarser sizes of crushed stone.

4.2.2 Moisture Content

The moisture content of fine deficient crushed stone was found to be 0.5% from laboratory test of the study.

4.2.3 Atterberg Limit

From the result obtained by conducting AASHTO T-89 & T-90 test methods for Atterberg limit, it was shown that the crushed stone sub-base material is non plastic (PI).

4.2.4 MDD and OMC

The laboratory test result that was obtained from MDD and OMC test conducted on fine deficient crushed stone sub-base material was shown on Figure 13.

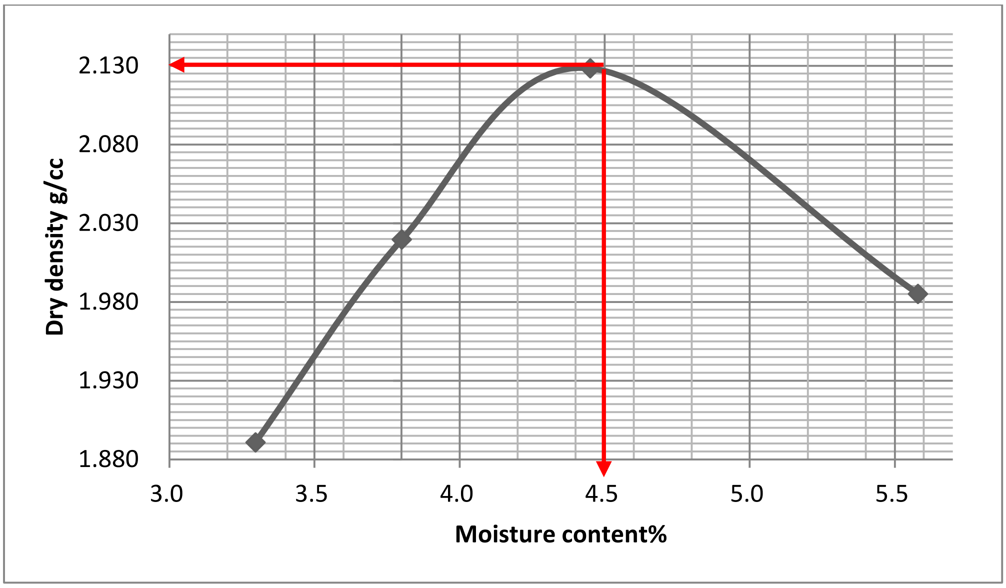


Figure 13: MDD and OMC result of Crushed Stone Sub-base material

From the Figure 13, the OMC of the material was 4.5 % whereas the MDD that could be achieved by compacting this material was 2.13 gm. /cc. The results showed that the material had a high MDD. It also showed that the material had average OMC. (Mhlongo, 2013)

4.2.5 CBR

A CBR value of at least 80% is typically required by ERA for a crushed sub-base material. Results presented in Figure 14 suggest that the crushed stone sub-base material meet the CBR requirements for usage as a sub-base material.

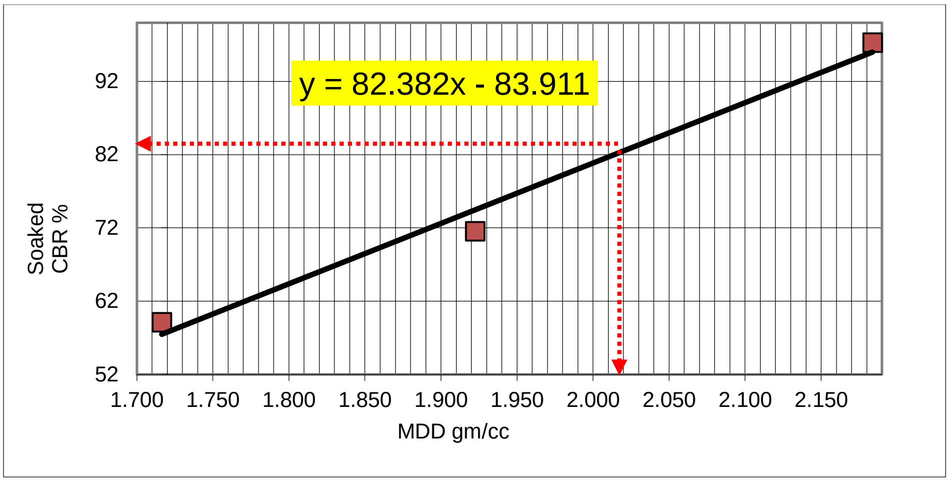


Figure 14: CBR of Crushed Stone Sub-base

4.2.6 LAA and F I

A LAA maximum value of 45 is normally adopted by ERA specifications for pavement sub-base materials (ERA, 2002).The LAA value of the crushed stone sub-base material is 23.2 4.This result showed that the crushed stone sub-base material meet the maximum criteria. This indicates that the crushed stone sub-base material are durable in abrasion. The flakiness index values for the crushed stone sub-base material is 24.9. This is however still within the requirements of ERA for usage as a crushed sub-base material, which specifies a maximum value of 35.

Generally the crushed stone sub-base material satisfies most of the requirements that are needed from sub-base material except that it is deficient with fine content. It is this problem that is necessary to be solved so as to make it usable for sub-base construction material.

4.3 Engineering Properties of the Blend of AMASSA Byproduct and the Fine Deficient Crushed Stone Sub-base material

The blending of the two materials was done by increasing the amount of AMASSA byproduct gradually starting from 3% then 6.5 and 10 % by mass of the fine deficient crushed stone sub-base material purposively depending on the graduation of the crushed stone sub-base material i.e. it was 2% fine content which was deficient by 3% to satisfy at least the lower limit 5% according to AASHTO T-27. The bases for choosing 3% was that the lower limit of the specific limit of the graduation of the crushed aggregate is 5%. So adding 3% to the original 2% finer than 75 µm material content of the crushed stone sub-base material could attain the lower limit, 5%. Whereas for the case of adding 6.5% of the byproduct to the crushed stone, it was with the aim of attaining 8.5% fine content, which is the mean value of the specific limit, of the crushed stone sub-base material. The last percentage of the byproduct added during the tests conducted for the blending was 10% so as to attain the upper specific limit, 12%, of the requirement of sub-base material. The results of the five tests conducted on the crushed stone sub-base material blended with AMASSA byproduct are presented in graphical forms as follows such that it is suitable for comparison of the effects 0%, 3% 6.5% and 10% by mass addition of the byproduct on the material property of the fine deficient crushed stone material.

4.3.1 Atterberg Limit Test

The plastic limit for the 3, 6.5 and 10% by mass addition of the byproduct to the crushed stone material were found to be NP, 32.33 and 34.6, respectively. Whereas the liquid limits for 6.5% and 10% addition of the byproduct are 33.33 and 41. 83 respectively. Based on the above result of the PL and LL of the blended materials, the results for PI were found to be NP, 1 and 7.23 for the three consecutive percentages of blends. These results are presented in the following chart starting from 0% of byproduct addition to 10% by mass of the crushed stone material.

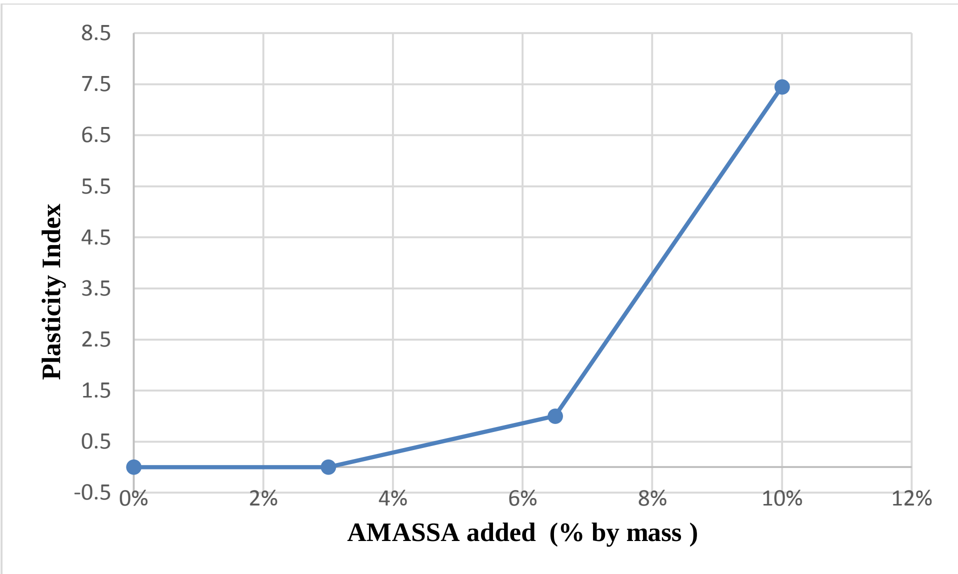


Figure 15: Plasticity vs. percentage of *AMASSA* added to the Crushed stone material

From the above graph, the Plasticity Index of the crushed stone material doesn't show any change, for the 3% by mass addition of the byproduct. It is NP, which is the same as the original unblended crushed stone material. Whereas the 6.5% increment of the byproduct increased the PI of the original unblended crushed stone material to 1. For the addition of the byproduct to the crushed stone by 10%, the PI showed huge increment that is 7.23.

According to the ERA technical specification manual, the Plasticity Index that is expected for crushed stone sub-base material is 0-6. Therefor our Plasticity Index graph showed that 10% addition of the byproduct was not acceptable. Due to this, the researcher avoided further examination of the engineering properties of the blended material for 10% addition of the byproduct. The rest of the experiments were conducted using 3 and 6.5% addition of the byproduct.

4.3.2 Particle Size Distribution

The following table shows particle size distribution of the crushed stone sub-base material blended with byproduct of AMASSA were conducted by a sieve analysis according to AASHTO T-27. The following table shows the percentage passing in each sieve sizes for the unblended and blended crushed stone material with the AMASSA byproduct.

Table 4: Particle size distribution of unblended, 3% blended and 6.5% blended

sieve Size(mm)	Percentage Passing for 0% blending	Percentage Passing for 3% blending	Percentage Passing for 6.5% blending	Lower Limit	Upper Limit
50.0	100.0	100.0	100.0	100.0	100.0
37.5	100.0	100.0	100.0	100.0	100.0
20.0	61.1	62.5	63.8	60.0	80.0
10.0	39.5	41.4	43.4	40.0	60.0
`5.0	26.3	28.7	31.1	25.0	40.0
2.4	14.0	16.3	19.1	15.0	30.0
0.4	6.4	9.4	12.4	7.0	19.0
0.1	2.1	5.2	8.4	5.0	12.0

The particle size distribution of the unblended crushed stone , 3% blended and 6.5% blended is presented in the following figure in graphical form for easy of comparison.

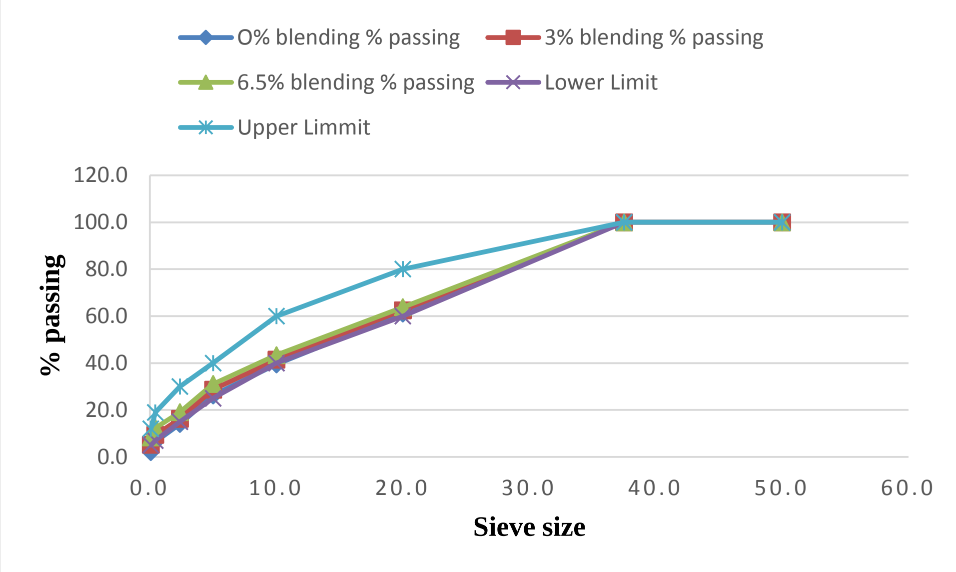


Figure 16: Particle size distribution of unblended, 3% blended and 6.5% blended

The particle size distribution table of the above three blending percentage of the byproduct to the crushed stone sub-base material shows that the unblended crushed stone material doesn’t satisfy the standard specific limits but the addition of 3% and 6.5% of the byproduct of AMASSA improved it in such a way that for every of the sieve sizes the material to be in between the lower and the upper limit of the specific limit for particle size distribution.

4.3.3 Moisture Content

The moisture content test result conducted for byproduct addition of 3% and 6.5% by mass of the crushed stone material are 0.9% and 1.3% respectively. The result of the moisture content from 0% addition up to 6.5% are presented graphically in the following figure for easy of comparison.

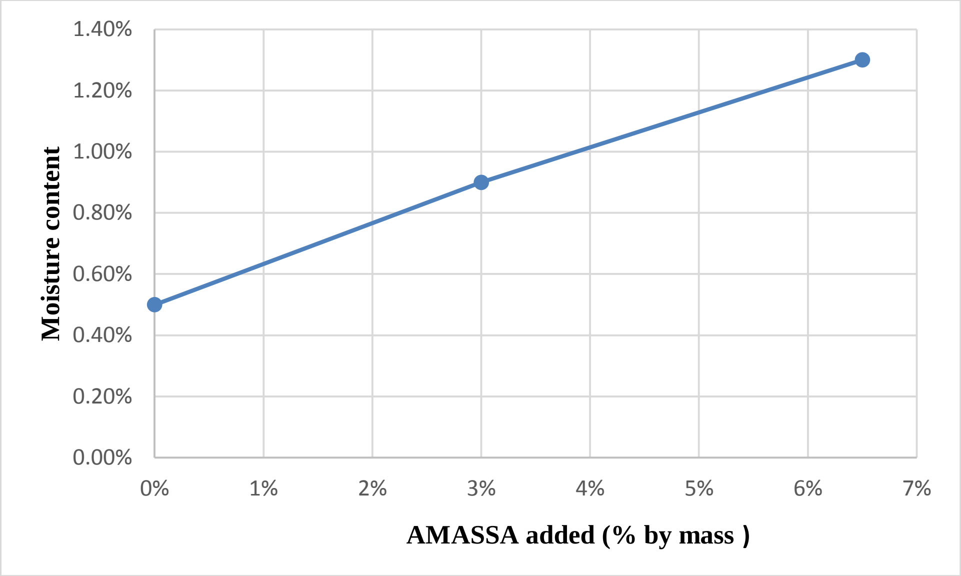


Figure 17: Moisture content Vs. Percentage of addition of byproduct to crushed stone material

From the above graph, the moisture content of the crushed stone material increased by 80% from the original one, for the 3% by mass addition of the byproduct. Whereas the 6.5% increment of the byproduct increased the moisture content of the original unblended crushed stone material by 160%.

4.3.4 MDD

The maximum dry density test result conducted for byproduct addition of 3% and 6.5% by mass of the crushed stone material are 2.17g/cc and 2.19g/cc respectively. The result of the moisture content from 0% addition up to 6.5% are presented graphically in the following figure for easy of comparison.

From Figure 18, the MDD of the crushed stone material increased by 1.88% from the original one, for the 3% by mass addition of the byproduct. Whereas the 6.5% increment of the byproduct increased, the MDD of the original unblended crushed stone material by 2.82%.

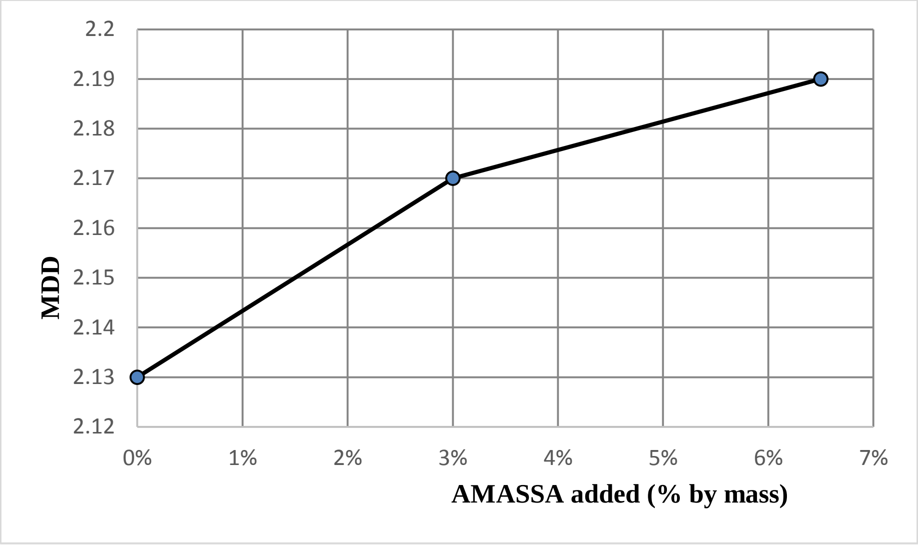


Figure 18: MDD vs. Percentage addition of byproduct to crushed stone material

4.3.5 OMC

The Optimum moisture content result for byproduct addition of 3% and 6.5% by mass of the crushed stone material are 7.6% and 11.2% respectively. The result of the moisture content from 0% addition up to 6.5% are presented graphically in the following figure for easy of comparison.

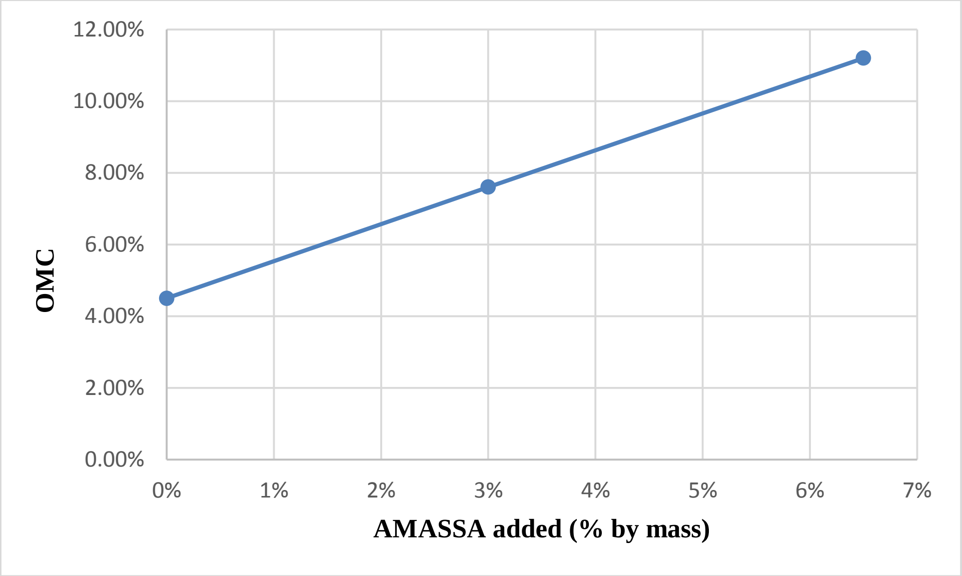


Figure 19: OMC vs. Percentage of byproduct addition to crushed stone material

From the above graph, the optimum moisture content of the crushed stone material increased by 69% from the original one, for the 3% by mass addition of the byproduct.

Whereas the 6.5% increment of the byproduct increased the OMC of the original unblended crushed stone material by 144.5%.

4.3.6 CBR

The CBR test result conducted for byproduct addition of 3% and 6.5% by mass of the crushed stone material are 102% and 112% respectively. The result of the moisture content from 0% addition up to 6.5% are presented graphically in the following figure for easy of comparison.

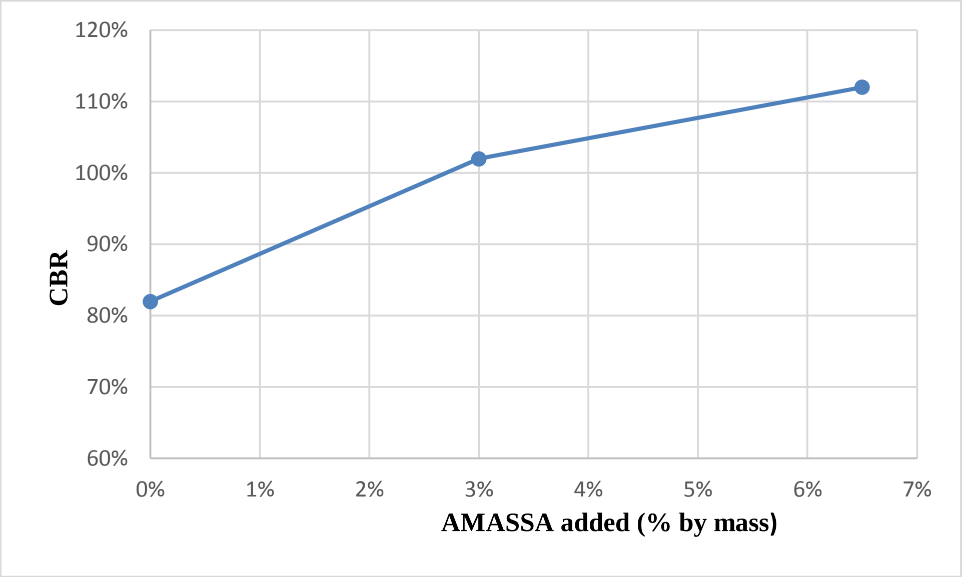


Figure 20: CBR vs. Parentage addition of byproduct to crushed stone material

From the above graph, the Californian Bearing Ratio of the crushed stone material increased by 23% from the original one, for the 3% by mass addition of the byproduct. Whereas the 6.5% increment of the byproduct increased the CBR of the original unblended crushed stone material by 35%.

Chapter 5: Conclusion and Recommendation

5.1 Conclusion

In this research, the results that were obtained in the analysis were concluded as follow:

The engineering properties of the byproduct of AMASSA that were determined are Particle size distribution, Moisture content, Specific gravity, Atterberg Limit Test, Maximum Dry Density, Optimum Moisture Content, California Bearing Ratio (CBR) and Organic Content. Regarding the particle size distribution, the material is found to pass 100% on the 75µm sieve size i.e. it is in the group of clay (silt) as per AASHTO M145 soil classification. The material had high moisture content as it's in the clay group. Based on the result of the PI, the experiments shown that it was plastic, which is the same as clay. When it comes to the specific gravity, it is 2.385. The MDD was found at a very high OMC and it was proven to be low. In addition to this, it was shown that the material is inorganic and with a small CBR value which makes it not suitable even to be a sub-grade material according to ERA specification.

Next to this the engineering properties of the fine deficient crushed stone sub-base material were determined. According to AASHTO T-27, the material was out of the specific limit range of particle size distribution. It was also shown that it is NP and with a moisture content of very low. It had a high MDD of 2.13g/cc at a low OMC of 4.5%. As per AASHTO specification of materials the fine deficient crushed stone also could satisfy the requirement of sub-base material regarding LAA and Flakiness Index.

As it is discussed above in depth about the laboratory experimental results of the blending of crushed stone sub-base material with AMASSA byproduct, five engineering properties of the crushed stone material are found to be affected. These are Plasticity Index, Particle Size Distribution, Moisture Content, Maximum Dry Density, Optimum Moisture Content and Californian Bearing Ratio.

In the first test of the experiment, the plasticity of the material is checked for the unblended crushed stone and the blended material with 3%, 6.5% and 10% by mass addition of the byproduct. From the graph of Plasticity Index of the crushed stone material, there was no change of PI shown for 3% by mass addition of the byproduct. It was NP, which is the same as the original unblended crushed stone material. Whereas the 6.5% increment of the byproduct increased the PI of the original unblended crushed stone material to 1. For the addition of the byproduct to the crushed stone by 10%, the PI showed huge increment. It became 7.4. But according to the ERA technical specification manual, the Plasticity Index that is expected from crushed stone sub-base material is 0-6. Therefor the experimental result showed that 10% addition of the byproduct is not acceptable for this fine deficient crushed stone material. Due to this, so further examination of the engineering properties of the blended material for 10% addition of the byproduct was avoided. The rest of the experiments were conducted using 3% and 6.5% addition of the byproduct. Based on this test, the maximum percentage of the byproduct to be added, so as not to make that plasticity Index of the crushed stone more than6, fails between 6.5% and 10% by mass of the crushed stone material.

The next parameter that was experimented is particle size distribution. The particle size distribution table of the three blending percentage of the byproduct to the crushed stone sub-base material shown that the unblended crushed stone material doesn't satisfy the standard specific limits according to AASHTO T-27 but the addition of 3% and 6.5% of the byproduct of AMASSA improved it in such a way that for every of the sieve sizes the material to be in between the lower and the upper limit of the specific limit for particle size distribution.

In the case of the experiment for moisture content of the crushed stone material, it increased by 80% from the original one for the 3% by mass addition of the byproduct. Whereas the 6.5% addition of the byproduct increased the moisture content of the original unblended crushed stone material by 160%.

Due to the blending process, the maximum dry density of the crushed stone material was increased by 1.88% from the original one for the 3% by mass addition of the byproduct. Whereas the 6.5% increment of the byproduct increased the MDD of the original unblended crushed stone material by 2.82%.In addition to the MDD the optimum moist content of the crushed stone material also increased by 69% from the original one for the 3% by mass addition of the byproduct. Whereas the 6.5% addition of the byproduct increased the OMC of the original unblended crushed stone material by 144.5%.

Finally the CBR value was found to be improved due the process. The CBR value of the crushed stone material increased by 23% from the original one, for the 3% by mass addition of the byproduct. Whereas the 6.5% addition of the byproduct increased the CBR of the original unblended crushed stone material by 35%.

Generally, as a result of the blending of the byproduct of AMASSA by 3% and 6.5% by mass of the crushed stone material, the particle size distribution of the fine deficient crushed stone was made to be in accordance with the ERA standard specification to be used as an appropriate sub-base material for highway construction. In addition to this, the blending process also improved the maximum dry density and the CBR value of the fine deficient crushed stone. The little increments on the moisture content and optimum moisture content are acceptable as they are in the acceptable range of the Standard technical specification of ERA too.

5.2 Recommendation

The main point of this research the improvement of the engineering properties of fine deficient crushed stone material to make it usable for sub-base construction of pavements by blending it with AMASSA byproduct up to 6.5% by mass. In doing so, the research shown that it is possible to use it for improvement of the particle size distribution of fine deficient crushed stone material with similar engineering properties. In addition to this it is also useful to improve sub-base materials which have problems in CBR and MDD as the blending process can increase them both by some amount.

On the side of the byproduct producer, it should encourage the application of the material to be used as a road making material as it can reduce the stockpiling and landfill expenses as well as places.

So as to make it more applicable in the field of highway construction, further researches are also necessary regarding the determination of the exact possible maximum percentage of the byproduct to be added to crushed stone material and the economic aspects of utilizing it in road sub-base construction.

Reference

1. American Association of State Highway and Transportation Officials. “AASHTO Guide for Design of Pavement Structures”. Washington D.C., 1993.
2. Ethiopian Road Authority Standard Technical Specification. ERA, Addis Ababa, 2002.
3. Haimanot, Feleke, Mesfin, “Removal of Azo Dye from water by Adsorption using Waste Residue from Alum Manufacturing process ” , 2014.
4. Disfani, MM, Arulrajah, A, Suthagaran, V & Bo, MW (2009a), ‘Geotechnical Characteristics of Recycled Glass-Biosolids Mixtures’, Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering held in Alexandria, Egypt, October 5-9, 2009, pp. 201-204.
5. WorkSafe-Victoria, 2006, Recycling Construction and Demolition Material, Guidance on Complying with the Occupational Health and Safety (Asbestos) Regulations 2003, WorkSafe, Melbourne, Australia.
6. Hoyos, L. R., Puppala, A. J., and Ordonez, C. A., 2011, “Characterization of Cement Fiber-Treated Reclaimed Asphalt Pavement Aggregates: Preliminary Investigation,” J. Mater. Civil Eng., ASCE, 23 (7), 977–989.
7. Taha, R., Al-Harthy, A., Al-Shamsi, K., and Al-Zubeidi, M. (2002). "Cement stabilization of reclaimed asphalt pavement aggregate for road bases and sub-bases." Journal of Materials in Civil Engineering, ASCE, 14(3), 239 - 245.
8. Arulrajah, A., Piratheepan, J., Aatheesan, T., and Bo, M. W., 2011, “Geotechnical Properties of Recycled Crushed Brick in Pavement Applications,” Journal of Materials in Civil Engineering. ASCE, 23 (10), 1444–1542.
9. Aatheesan, T., Arulrajah, A., Bo, M. W., Vuong, B., and Wilson, J., 2010, “Crushed Brick Blends With Crushed Rock for Pavement Systems,” Proc. Inst. Civil Eng. (UK), Waste Res. Manage. 163 (1), 29–35.
10. Poon, C. S., and Chan, D. (2006). "Feasible use of recycled concrete aggregates and crushed clay brick as unbound road sub-base." Construction and Building Materials 20, 578–585.
11. Debieb, F. and Kenai, S., 2008, “The Use of Coarse and Fine Crushed Bricks as Aggregate in Concrete,” Construction and Building Materials. 22, 886–893.
12. Gregory, R. J., Hughes, T. G., and Kwan, A. S. K. (2004). “Brick recycling and reuse.” Engineering Sustainability, Proc., Institution of Civil Engineers UK, 157(ES3), London, 155–161.

13. Wartman, J, Grubb, DG &Nasim, ASM (2004), ‘Select engineering characteristics of crushed glass,’ Journal of Materials in Civil Engineering, 16 (6), 526-539.
14. McKelvey, D., Sivakumar, V., Bell, A., and McLaverty, G., 2002, “Shear Strength of Recycled Construction Materials Intended for Use in Vibro Ground Improvement,” Ground Improvement, Proc. Inst. Civil Eng., U.K., 6 (2), 59–68.
15. Tao, M., Mohammad, L. N., Nazzal, M. D., Zhang, Z., and Wu, Z. (2010). "Application of shakedown theory in characterizing traditional and recycled pavement base materials." ASCE'sJournal of Transportation Engineering, 16(3), 214 - 222.
16. Saride, S., Puppala, A. J., and Williammee, R. (2010). "Assessing recycled/secondary materials as pavement bases." Ground Improvement, Proceedings of the Institution of Civil Engineers, UK, 163, 3 - 12.
17. Tam, V. W. Y. and Tam, C. M., 2006, “A Review on the Viable Technology for Construction Waste Recycling,” Res., Conserv. Recycling, 47, 209–221.
18. Farhad Reza, Ph.D.,P.E, “ Use of Recycled Brick in Aggregates,” 2013.
19. Yoder, E. J. and Witczak, Principles of pavement design, 1975.
20. Standard Specification for AACRA Urban Infrastructure Works, February, 2003.
21. Dr.J.Jha and S.K.Sinha Construction and Foundation Engineering, 1998.
22. S’Phamandla Mulngisi Mhlongo “Recycling of Construction Waste for Road Rehabilitayion ”, 2013.
23. ERA Standard Technical Specification and Method of Measurement, 2013
24. P.V.V Satyanarayana“A Study on the Use of Crushed Stone Aggregate and Crusher Dust Mixes in Flexible Pavements”, 2013.
25. Paul, R., and Warwick, R. (1996). "Use of recycled crushed concrete for road and pavement sub-base." *Proc., 18th ARRB Conf., Australia*, Road Research Board, Christchurch, N.Z, 93–106.
26. Park, T. (2003).). "Application and Building Debris as Base and Sub-base materials in Ridged Pavement." Journal of Transportation Engineering, 129(5), 558-563.
27. Papagiannakis, A. T., and Masad, E. A. (2007). *Pavement design and material*, New Jersey: John Wiley & sons.
28. Ooi, P. S. K., Li, M. M. W., Sagario, M. L. Q., and Song, Y. (2008). "Shear Strength Characterstics of Recycled Glass.” Transportation Research Record, 2059, 52-62.
29. Landris, T. L. (2007). "Recycled glass and dredged materials." US Army Corps of Engineers: Engineer Research and Development Center Report ERDC TN-DOER-T8, Vicksburg, MS.

30. Azam, A. M., and Cameron, D. A. (2012). "Geotechnical properties of blends of Recycled clay Masonary and Recycled concrete Aggregate in Unbound Pavement Construction." Journal of Materials in Civil Engineering, ASCE. Article in press.
31. Gabr, A., and Cameron, D. (2012). "Properties of Recycled Concrete Aggregate for Unbound Pavement Construction." *Journal of Materials in Civil Engineering*, 24(6), 754–764.
32. Akbulut, H., and Gurer, C. (2007). "Use of aggregates produced from marble quarry waste in asphalt pavements." *Journal of Building and Environment*, 42, 1921-1930.
33. O'Flaherty, F. (2008). “Physical properties of demolit ion waste material.” *Proc. Institution of Civil Engineers: Construction Mater*. 161(3), 97-103.

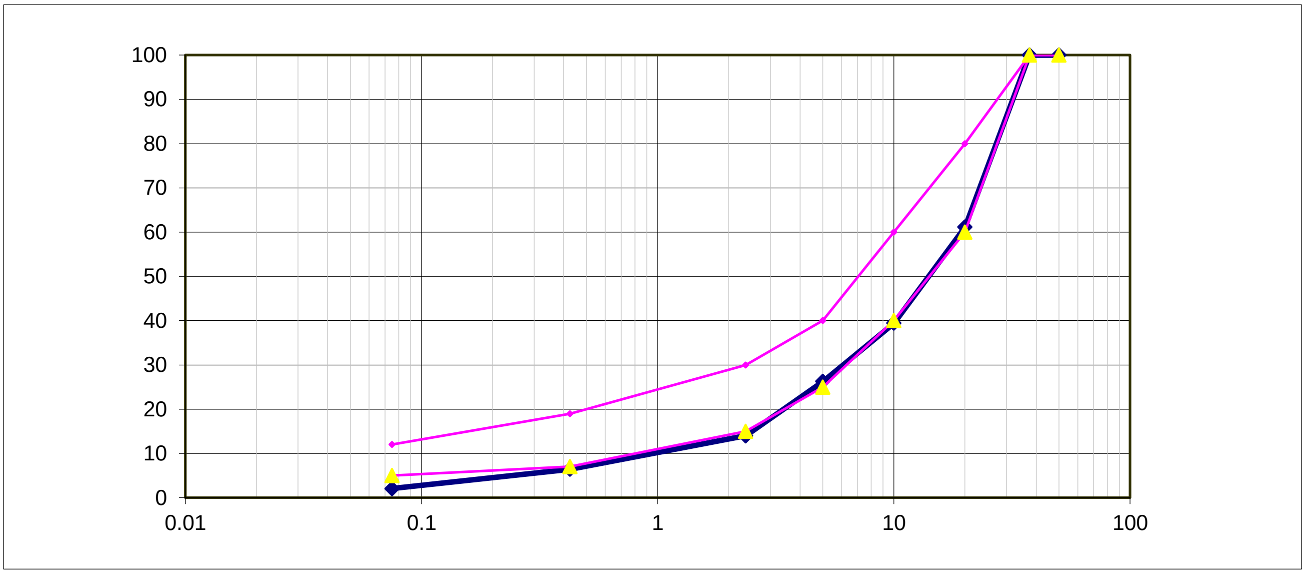
Appendix A

1) Particle Size Distribution of the byproduct of AMASSA

sieve size, mm.	% passing
4.75mm	100
2.36mm	100
0.425mm	100
0.075mm	100

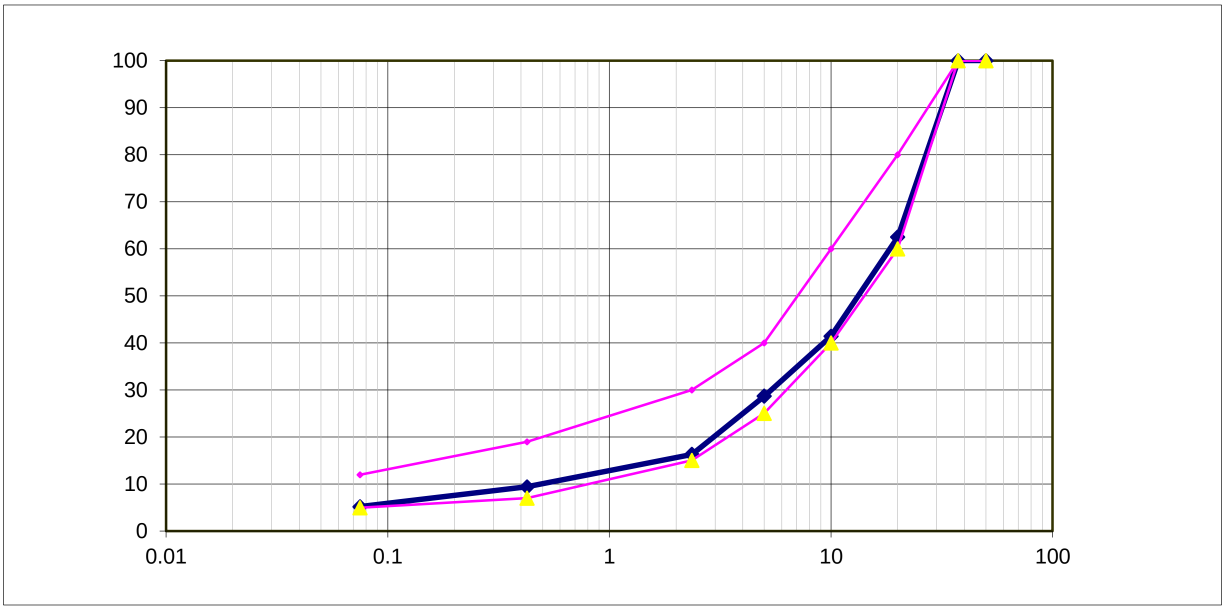
2) Particle Size Distribution of the crushed stone sub base

sieve size, mm.	weight retained (Partial)	% retained	% passing	Lower Limit	Upper Limit
50	0	0	100	100	100
37.5	0.0	0.0	100.0	100	100
20	5716.0	38.9	61.1	60	80
10	3191.5	21.7	39.5	40	60
5	1941.9	13.2	26.3	25	40
2.36	1802.1	12.2	14.0	15	30
0.425	1111.3	7.6	6.4	7	19
0.075	643.6	4.4	2.1	5	12
Pan	0.0				
Dry weight after washing	14406.3gm.	100.0			
Dry weight before washing	14711.6 gm.				



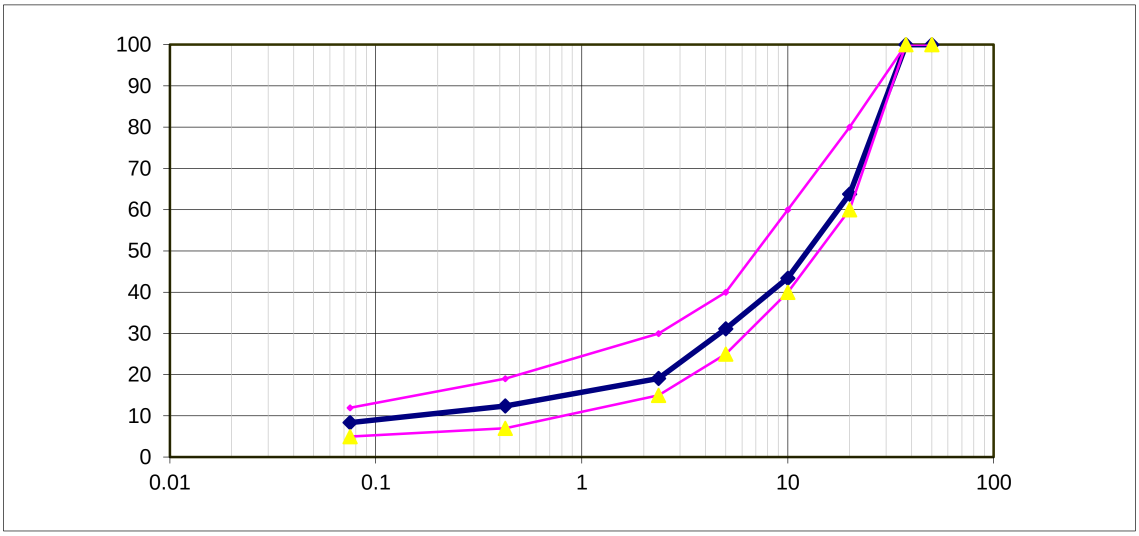
3) Particle Size Distribution of the 3% blended crushed stone sub base

sieve size, mm.	weight retained (Partial)	% retained	% passing	Lower Limit	Upper Limit
50	0	0	100	100	100
37.5	0.0	0.0	100.0	100	100
20	5000.4	37.5	62.5	60	80
10	2813.5	21.1	41.4	40	60
5	1693.5	12.7	28.7	25	40
2.36	1653.5	12.4	16.3	15	30
0.425	920.1	6.9	9.4	7	19
0.075	560.0	4.2	5.2	5	12
Pan	0.0				
Dry weight after washing	12640.9 gm.	100.0			
Dry weight before washing	13334.3 gm.				



4) Particle Size Distribution of the 6.5% blended crushed stone sub base

sieve size, mm.	weight retained (Partial)	% retained	% passing	Lower Limit	Upper Limit
50	0	0	100	100	100
37.5	0.0	0.0	100.0	100	100
20	4946.0	36.2	63.8	60	80
10	2787.3	20.4	43.4	40	60
5	1680.6	12.3	31.1	25	40
2.36	1639.6	12.0	19.1	15	30
0.425	915.4	6.7	12.4	7	19
0.075	550.2	4.0	8.4	5	12
Pan	0.0				
Dry weight after washing	12519.1gm.	100.0			
Dry weight before washing	13663.1 gm.				



Appendix B

1) Natural moisture content of a byproduct of AMASSA

Natural moisture content		
can number	AK	AO
Mass Of Moisture can (Mc)	68.8	72.4
Mass of moisture can + Mass of moist soil (Mcms)	321	298.2
Mass of Moisture can + mass of oven dried soil(Mcds)	298.5	278.4
Mass of water (Mw)	22.5	19.8
Mass of dry soil (Ms)	229.7	206
Water Content(w) %	9.8	9.6
Average water content(w) %	9.7	

2) Natural moisture content of crushed stone sub base

Natural moisture content		
can number	G2	AO
Mass Of Moisture can (Mc)	75.7	76.4
Mass of moisture can + Mass of moist soil (Mcms)	315.6	302.2
Mass of Moisture can + mass of oven dried soil(Mcds)	314.3	301.1
Mass of water (Mw)	1.3	1.1
Mass of dry soil (Ms)	238.6	224.7
Water Content(w) %	0.54	0.49
Average water content(w) %	0.5	

3) Natural moisture content of the 3% blended crushed stone sub base

Natural moisture content		
can number	CK	101
Mass Of Moisture can (Mc)	72.1	76.2
Mass of moisture can + Mass of moist soil (Mcms)	257.2	291.4
Mass of Moisture can + mass of oven dried soil(Mcds)	255.6	289.5
Mass of water (Mw)	1.6	1.9
Mass of dry soil (Ms)	183.5	213.3
Water Content(w) %	0.87	0.89
Average water content(w) %	0.9	

4) Natural moisture content of the 6.5% blended crushed stone sub base

Natural moisture content		
can number	A01	B13
Mass Of Moisture can (Mc)	69.4	64.5
Mass of moisture can + Mass of moist soil (Mcms)	246.5	249.8
Mass of Moisture can + mass of oven dried soil(Mcds)	244.4	247.3
Mass of water (Mw)	2.1	2.5
Mass of dry soil (Ms)	175	182.8
Water Content(w) %	1.20	1.37
Average water content(w) %	1.3	

Appendix C

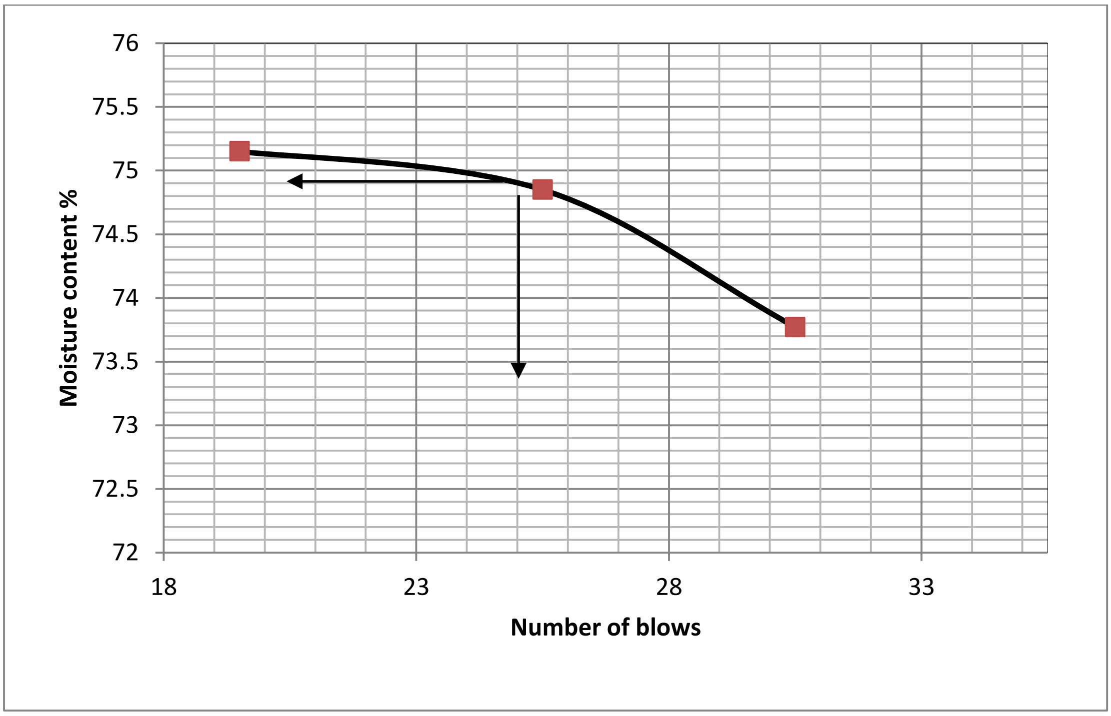
Specific gravity of the byproduct of AMASSA

Sample Site	1	2
Mass of Pycnometer, Mp	180.3	175.9
Mass of Pycnometer + Soil, Mps	280.5	275.9
Mass of Pycnometer + Soil + Water, Mpws	806.5	806.4
Mass of Pycnometer + Water, Mpw @ Ti	747.2	747.5
The water temprature, Ti	24^0C	24^0C
Temperature of contents of Pycnometer When Mpws was taken, Tx	18.5^0C	18.5^0C
Mass of Dry Soil, Ms	100	100
Density of water at Ti, **ρw @ Ti**	0.9972995	0.9972995
Density of water at Tx**ρw @ Tx**	0.9985048	0.9985048
Conversion factor, K	0.9982071	0.9982071
Specific Gravity, @ 20^oc Gs =	2.380	2.391
	Average	**2.385**

Appendix D

1) Atterberg Limit Test of a byproduct of AMASSA

Liquid Limit			
Container No.	ms	A2	co
Wt of wet soil + container, gm	50.40	48.80	48.00
Wt of dry soil + container, gm	36.90	36.30	35.60
Wt of water	13.50	12.50	12.40
Wt of container	18.60	19.60	19.10
Wt of dry soil, gm	18.30	16.70	16.50
Water content, %	73.77	74.85	75.15
No. of blows	30	25	19



Plastic Limit			
Container No.	16	20	**Average**
Wt of wet soil + container, gm	21.50	20.90	
Wt of dry soil + container, gm	20.00	19.20	
Wt of water	1.50	1.70	
Wt of container	17.50	16.50	
Wt of dry soil, gm	2.50	2.70	
Water content, %	60.00	62.96	**62**

Liquid Limit	74.9
Plastic Limit	62
Plasticity Index	12.9

2) Atterberg Limit Test of crushed stone sub base

Liquid Limit			
Container No.			
Wt of wet soil + container, gm			
Wt of dry soil + container, gm			
Wt of water			
Wt of container			
Wt of dry soil, gm			
Water content, %			
No. of blows			

Plastic Limit			
Container No.			**Average**
Wt of wet soil + container, gm			
Wt of dry soil + container, gm			
Wt of water			
Wt of container			
Wt of dry soil, gm			
Water content, %			**0**

Non Plastic

Liquid Limit	0
Plastic Limit	0
Plasticity Index	0

3) Atterberg Limit for 3% blended crushed stone sub base

Liquid Limit			
Container No.			
Wt of wet soil + container, gm			
Wt of dry soil + container, gm			
Wt of water			
Wt of container			
Wt of dry soil, gm			
Water content, %			
No. of blows			

Non Plastic

Plastic Limit			
Container No.			**Average**
Wt of wet soil + container, gm			
Wt of dry soil + container, gm			
Wt of water			
Wt of container			
Wt of dry soil, gm			
Water content, %			**0**

Liquid Limit	0
Plastic Limit	0
Plasticity Index	0

4) Atterberg Limit for 6.5% blended crushed stone sub base

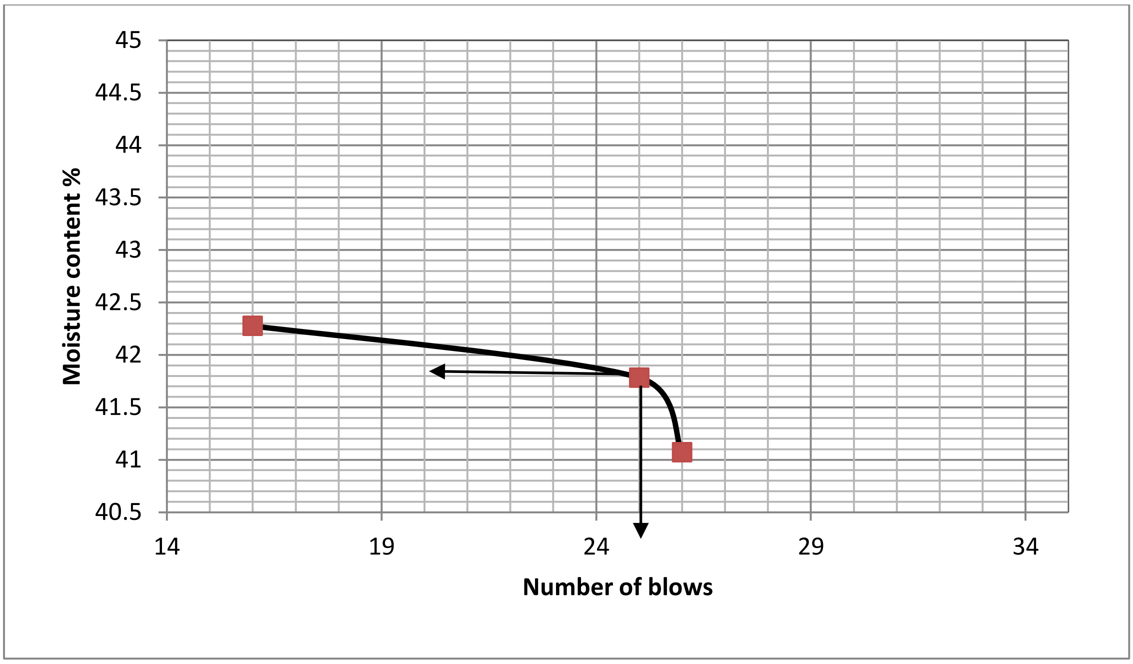
5) Liquid Limit			
Container No.	ms	A2	co
Wt. of wet soil + container, gm.	45.50	46.80	51.20
Wt. of dry soil + container, gm.	40.20	40.20	46.30
Wt. of water	5.30	6.60	4.90
Wt. of container	23.80	20.40	32.00
Wt. of dry soil, gm.	16.40	19.80	14.30
Water content, %	32.32	33.33	34.27
No. of blows	31	25	18

Plastic Limit			
Container No.	2	16	**Average**
Wt of wet soil + container, gm	15.10	14.70	
Wt of dry soil + container, gm	14.10	13.70	
Wt of water	1.00	1.00	
Wt of container	11.00	10.60	
Wt of dry soil, gm	3.10	3.10	
Water content, %	32.26	32.26	**32.3**

Liquid Limit	33.33
Plastic Limit	32.33
Plasticity Index	1

5) Atterberg Limit for 10% blended crushed stone sub base

Liquid Limit			
Container No.	ms	A2	co
Wt. of wet soil + container, gm.	47.50	50.70	49.50
Wt. of dry soil + container, gm.	40.60	41.80	44.30
Wt. of water	6.90	8.90	5.20
Wt. of container	23.80	20.50	32.00
Wt. of dry soil, gm.	16.80	21.30	12.30
Water content, %	41.07	41.78	42.28
No. of blows	26	25	16

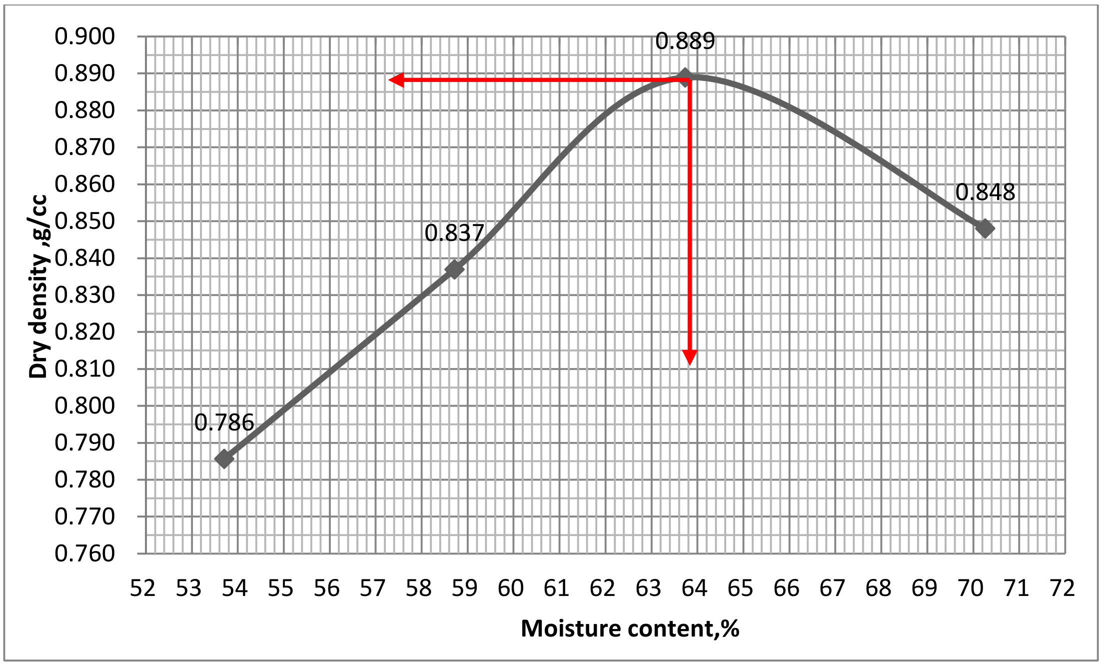


Plastic Limit			
Container No.	2	16	**Average**
Wt of wet soil + container, gm	24.80	23.40	
Wt of dry soil + container, gm	23.70	22.60	
Wt of water	1.10	0.80	
Wt of container	20.50	20.30	
Wt of dry soil, gm	3.20	2.30	
Water content, %	34.38	34.78	**34.6**

Liquid Limit	41.83
Plastic Limit	34.6
Plasticity Index	7

Appendix E

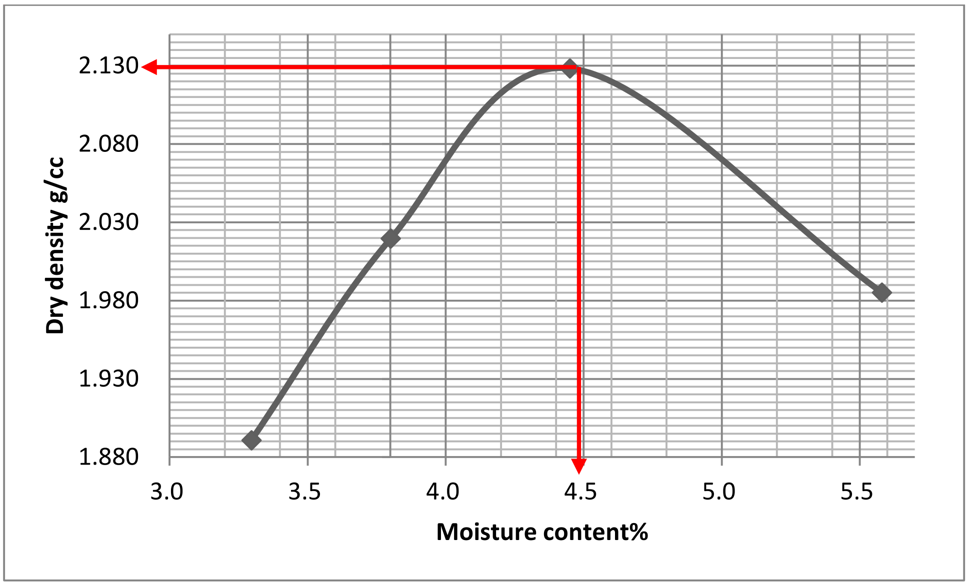
1) MDD and OMC of a byproduct of AMASSA



- No. of blows=25, No Layers=5, Proportion Retained on 19mm sieve size , (Pass 50mm sieve and retained on 19mm sieve), Weight of hammer, kg= 4.5, Volume of mold, cm3= 944

A	Mold	No.	1	2	3	4
B	Wt. of Mold + Wet Soil	grams	4059.0	4173.0	4293.0	4282.0
C	Wt. of Mold	grams	2919.0	2919.0	2919.0	2919.0
D	Wt. Wet Soil	grams	1140.0	1254.0	1374.0	1363.0
E	Volume of Mold	cu.cm.	944.0	944.0	944.0	944.0
F	Wet Density	gm./cc	1.208	1.328	1.456	1.444
G	Container	No.	AB1	AO	AC1	AF
H	Wt. Cont + Wet soil	grams	302.0	284.4	293.1	310.0
I	Wt. Cont + Dry soil	grams	223.8	206.6	206.1	214.3
J	Weight of Water	grams	78.2	77.8	87.0	95.7
K	Weight of Container	grams	78.2	74.1	69.6	78.1
L	Weight of Dry Soil	grams	145.6	132.5	136.5	136.2
M	Moisture Content	%	53.7	58.7	63.7	70.3
N	Dry Density	gm./cc	0.786	0.837	0.889	0.848

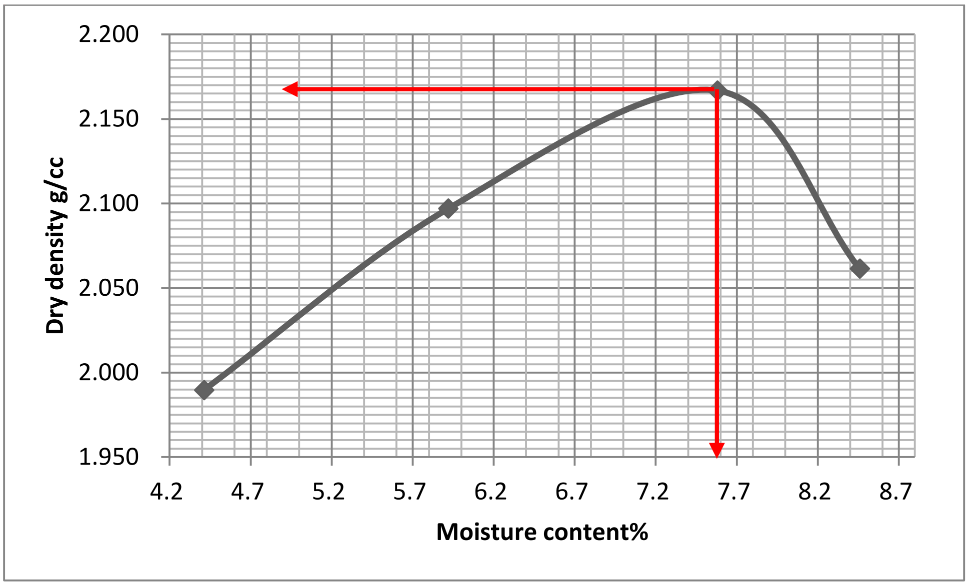
2) MDD and OMC of Fine Deficient Crushed Stone Sub-base material



- No. of blows=56, No Layers=5, Proportion Retained on 19mm sieve size , (Pass 50mm sieve and retained on 19mm sieve), Weight of hammer, kg= 4.5, Volume of mold, cm3= 2123

A	Mold	No.	1	2	3	4
B	Wt. of Mold + Wet Soil	grams	10395.8	10700.0	10969.0	10699.0
C	Wt. of Mold	grams	6249.5	6249.5	6249.5	6249.5
D	Wt. Wet Soil	grams	4146.3	4450.5	4719.5	4449.5
E	Volume of Mold	cu.cm.	2123.0	2123.0	2123.0	2123.0
F	Wet Density	gm./cc	1.953	2.096	2.223	2.096
G	Container	No.	D6	F5	A12	C11
H	Wt. Cont + Wet soil	grams	237.8	247.2	235.3	248.2
I	Wt. Cont + Dry soil	grams	231.3	239.4	226.8	236.9
J	Weight of Water	grams	6.5	7.8	8.5	11.3
K	Weight of Container	grams	34.1	34.2	35.8	34.4
L	Weight of Dry Soil	grams	197.2	205.2	191.0	202.5
M	Moisture Content	%	3.3	3.8	4.5	5.6
N	Dry Density	gm./cc	1.891	2.020	2.128	1.985

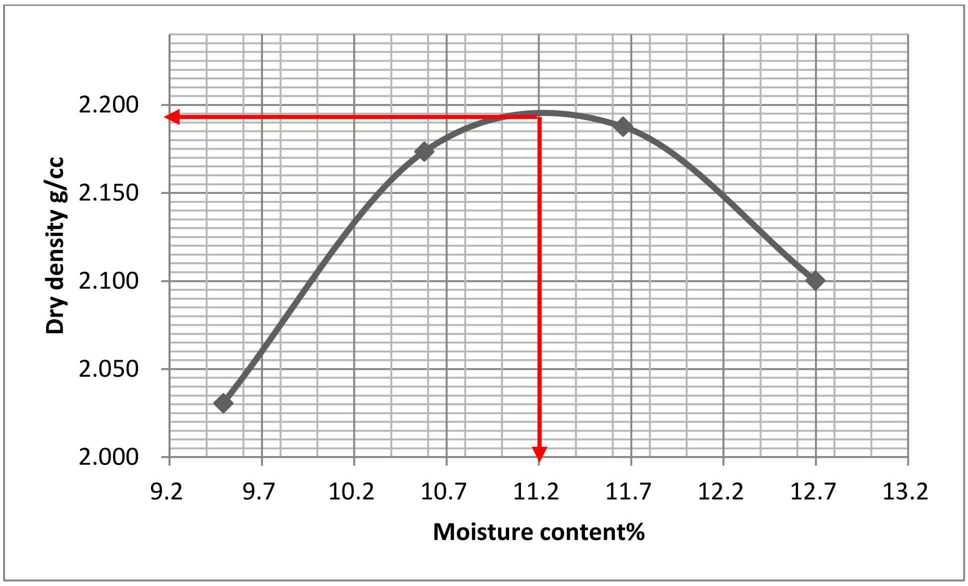
3) MDD and OMC of 3% Blended Crushed Stone sub-base



- No. of blows=56, No Layers=5, Proportion Retained on 19mm sieve size , (Pass 50mm sieve and retained on 19mm sieve), Weight of hammer, kg= 4.5, Volume of mold, cm3= 2123

A	Mold	No.	1	2	3	4
B	Wt. of Mold + Wet Soil	grams	10661.1	10966.1	11199.5	10997.3
C	Wt. of Mold	grams	6250.7	6250.7	6250.7	6250.7
D	Wt. Wet Soil	grams	4410.4	4715.4	4948.8	4746.6
E	Volume of Mold	cu.cm.	2123.0	2123.0	2123.0	2123.0
F	Wet Density	gm./cc	2.077	2.221	2.331	2.236
G	Container	No.	D6	F5	A12	C11
H	Wt. Cont + Wet soil	grams	198.1	198.7	196.0	198.9
I	Wt. Cont + Dry soil	grams	191.2	189.5	184.6	186.0
J	Weight of Water	grams	6.9	9.2	11.4	12.9
K	Weight of Container	grams	34.8	34.1	34.2	33.5
L	Weight of Dry Soil	grams	156.4	155.4	150.4	152.5
M	Moisture Content	%	4.4	5.9	7.6	8.5
N	Dry Density	gm./cc	1.990	2.097	2.167	2.061

4) MDD and OMC of 6.5% Blended Crushed Stone sub-base



- No. of blows=56, No Layers=5, Proportion Retained on 19mm sieve size , (Pass 50mm sieve and retained on 19mm sieve), Weight of hammer, kg= 4.5, Volume of mold, cm3= 2123

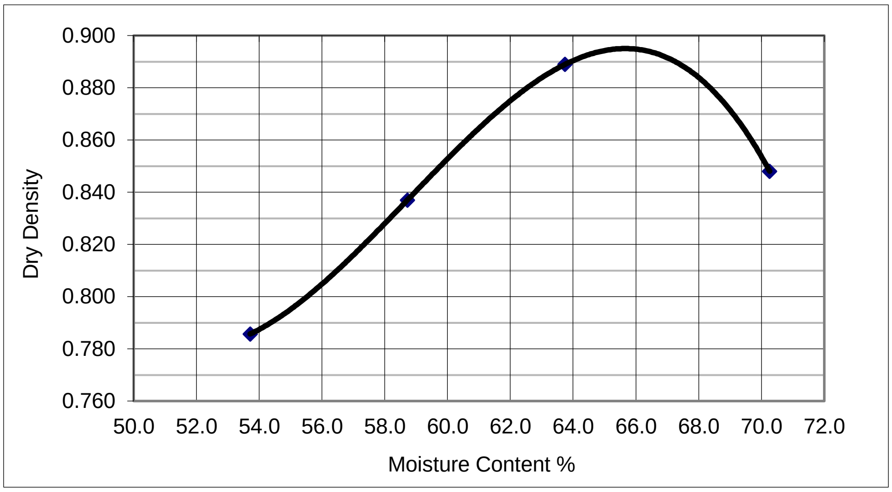
A	Mold	No.	1	2	3	4
B	Wt. of Mold + Wet Soil	grams	10809.4	11191.5	11275.0	11114.2
C	Wt. of Mold	grams	6089.4	6089.4	6089.4	6089.4
D	Wt. Wet Soil	grams	4720.0	5102.1	5185.6	5024.8
E	Volume of Mold	cu.cm.	2123.0	2123.0	2123.0	2123.0
F	Wet Density	gm./cc	2.223	2.403	2.443	2.367
G	Container	No.	D6	F5	A12	C11
H	Wt. Cont + Wet soil	grams	202.8	214.2	217.8	228.3
I	Wt. Cont + Dry soil	grams	188.1	197.0	199.0	206.5
J	Weight of Water	grams	14.7	17.2	18.8	21.8
K	Weight of Container	grams	33.2	34.4	37.7	34.8
L	Weight of Dry Soil	grams	154.9	162.6	161.3	171.7
M	Moisture Content	%	9.5	10.6	11.7	12.7
N	Dry Density	gm./cc	2.031	2.173	2.188	2.100

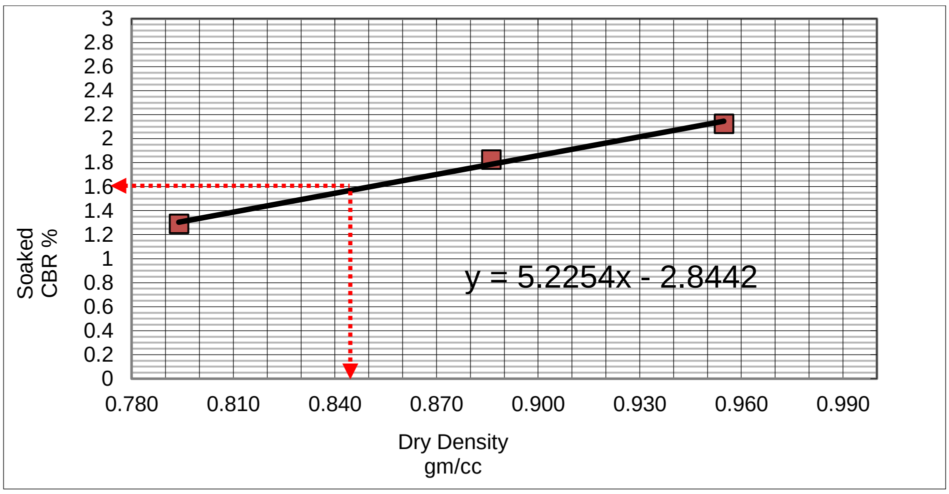
Appendix F

1) CBR for byproduct of AMASSA

No.	1	2	3	4
Moisture content %	53.71	58.72	63.74	70.26
Dry Density gm./cc	0.786	0.837	0.889	0.848
MDD	0.889			
OMC	64			

3 point CBR			
No. of Blows	Dry Density gm./cc	Soaked CBR	Swell %
10	0.794	1	1.75
30	0.886	2	1.39
65	0.955	2	1.12

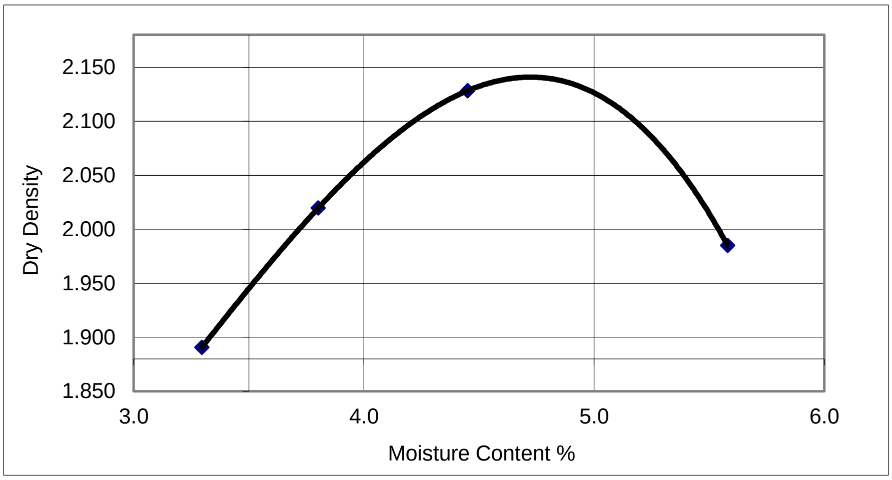


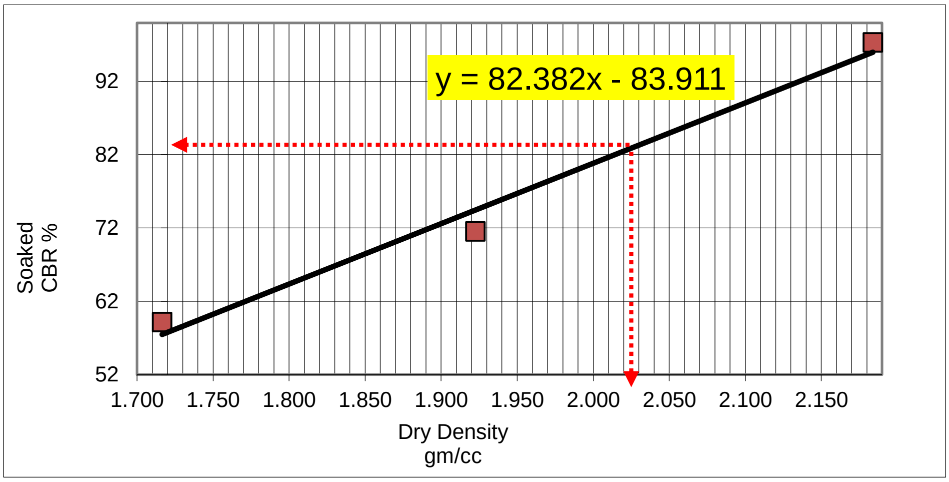


2) CBR for byproduct fine deficient crushed stone sub-base

No.	1	2	3	4
Moisture content %	3.30	3.80	4.45	5.58
Dry Density gm./cc	1.891	2.020	2.128	1.985
MDD	2.130			
OMC	4.5			

3 point CBR			
No. of Blows	Dry Density gm./cc	Soaked CBR	Swell %
10	1.716	59	0.00
30	1.923	72	0.00
65	2.184	97	0.00

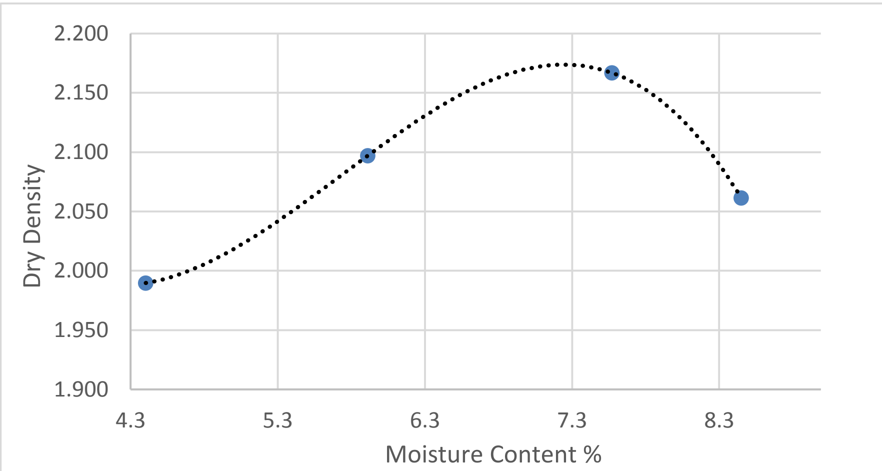


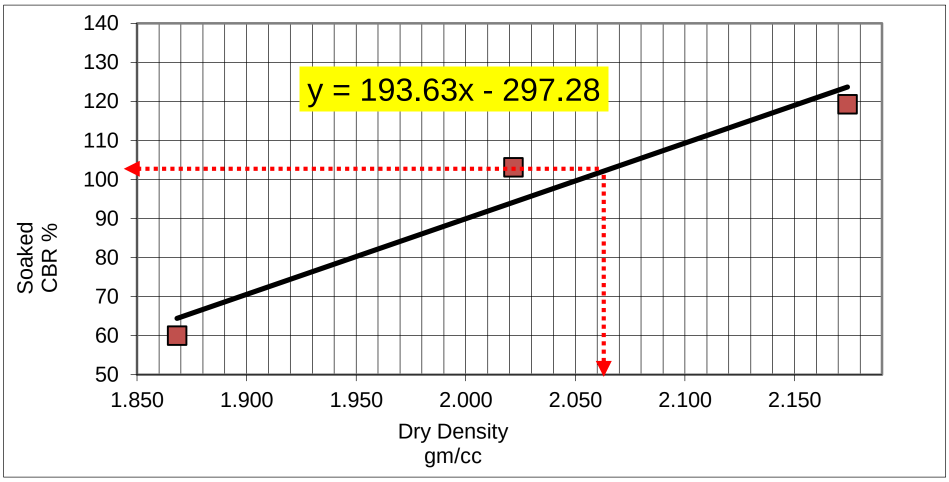


3) CBR for 3% blended crushed stone

No.	1	2	3	4
Moisture content %	4.41	5.92	7.58	8.46
Dry Density gm./cc	1.990	2.097	2.167	2.061
MDD	2.170			
OMC	7.6			

3 point CBR			
No. of Blows	Dry Density gm./cc	Soaked CBR	Swell %
10	1.868	60	0.00
30	2.022	103	0.00
65	2.174	119	0.00

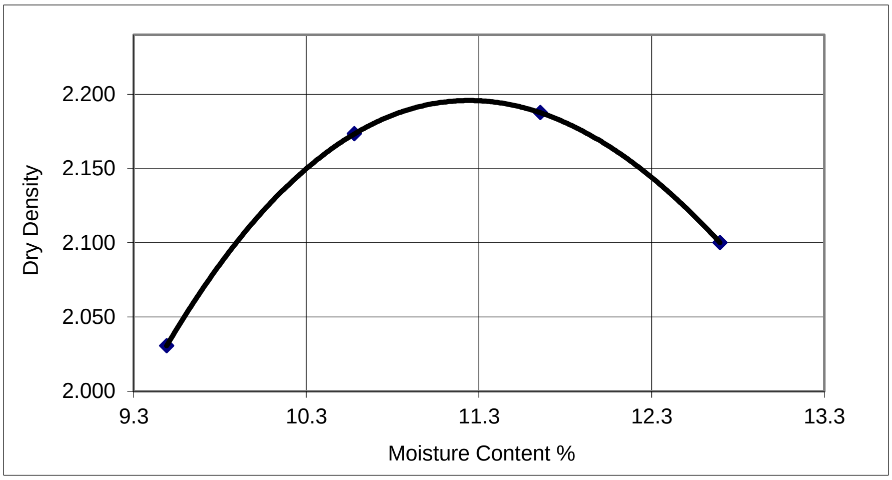


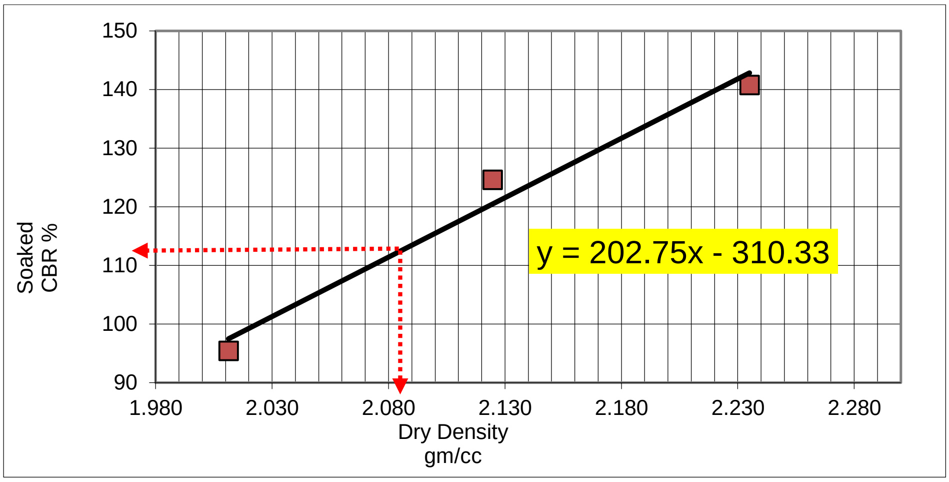


4) CBR for 6.5% blended crushed stone

No.	1	2	3	4
Moisture content %	9.49	10.58	11.66	12.70
Dry Density gm./cc	2.031	2.173	2.188	2.100
MDD	2.190			
OMC	11.2			

3 point CBR			
No. of Blows	Dry Density gm./cc	Soaked CBR	Swell %
10	2.011	95	0.00
30	2.125	125	0.00
65	2.235	141	0.00





Appendix G

Flakiness Index of Fine Deficient Crushed Stone Sub-base Material

Sieves Nominal Aperture Size, mm.	Mass of test portion '(gm)	Mass of agg. Passing on the flakiness gauge (gm)	Flakiness Index (%)	% in the total aggregate %	Weighted average flakiness index %
50.0 - 63.0					
37.5 - 50.0					
25.0 - 37.5	652.0	150	23.0	260.8	60.0
19.0 - 25.0	2000.0	502	25.1	37.0	9.3
13.2 - 19.0	1500.0	413	27.5	27.8	7.6
9.50 - 13.2	1000.0	204	20.4	18.5	3.8
6.3 - 9.50	250	75	30.0	4.6	1.4
TOTAL WEIGHT	5402.0	1344			22.1
FLAKINESS INDEX	**24.9**				

Appendix H

LAA of Fine Deficient Crushed Stone Sub-base Material

Sieve Size (SquareOpenings)		Mass of Indicated Size, (g) Grading				Wt. of sample to be tested	
Passing	Retained on	**A**	**B**	**C**	**D**	Trial 1	Trial 2
37	25						
25	20						
20	12.5		2501			2501	2500
12.5	9.5		2500			2500	2500
Total			5001			5001	5000
Number of Spheres (Balls) used			11			**11**	

Test Result Analysis		
Trial	Trial1	Trial2
Number of Revolution	500	500
Total Wt of Sample Tested(W)	5001	5000
Wt. of Tested Sample Retained On 1.70 mm Sieve(X)	3877	3800
Loss in grams Y=(W-X)	1124	1200
Percent Loss Z=(Y/M)*100	22.48	24.00
Average Percent Loss ＝ Trial1 + Trial2) /2	23.24	