# FEASIBILITY STUDY OF USE OF BOTTOM ASH, BY PRODUCT OF NOROCHCHOLI COAL POWER PLANT IN HOT MIX ASPHALT CONCRETE IN SRI LANKA


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Thesis/Dissertation submitted in partial fulfilment of the requirements for the degree

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# Abstract

A review of recent research on bottom ash seems to indicate it has the capability to improve asphalt pavement performance when used to replace a portion of the aggregate in asphalt mixes. Bottom ash can be used as an aggregate replacement, providing a substantial savings to both highway agencies and utility companies. Bottom ash has been used as fine aggregates in asphalt paving mixtures since the early 1970's. The American Coal Ash Association reported that, over 17,200 metric tons of bottom ash was used in asphalt paving during 2006.

The research is focused on investigation of properties of bottom ash, which is the byproduct of Norochcholai coal power plant and feasibility study of use of bottom ash in hot mix asphalt concrete in Sri Lankan roads. According to the results obtained, the best mixtures are produced by blending bottom ash with well-graded, angular, rough-textured aggregate and limiting the percentage of bottom ash to 25% for wearing and 16% for binder course. Marshall Stability and flow values have been found to decrease as the percentage of Wet bottom ash is increased in the mixture.

Further, high percentage of bottom ash replacement increases optimum bitumen content, which mainly affects to high production cost. Although the cost per 1 Mt of bottom ash blended mix is higher than the conventional mix for both surface courses, its low density increases overlay area. Because of that the cost per 1 $m^2$ is lower than the conventional mix. The successful use of bottom ash in asphalt pavements in Sri Lanka would provide not only significant economic savings but also an environmental friendly solution for a waste material.

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## LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| AIV | Aggregate Impact Value |
| ASTM | American Society for Testing and Materials |
| BC | Binder Course |
| FGD | Flue Gas Desulfurization |
| FI | Flakiness Index |
| HMA | Hot Mix Asphalt |
| HSR | Highway Rate of Schedule |
| LAAV | Los Angeles Abrasion Value |
| SCR | Selective Catalytic Reduction |
| SSCM | Standard Specifications of Construction Materials |
| USA | United State of America |
| VIM | Voids in Mixture |
| VMA | Voids in Mineral Aggregates |
| WC | Wearing Course |

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# CHPTER 1
# INTRODUCTION

## 1.1 General Background

Traditionally soil, stone aggregates, sand, bitumen and cement are used for road construction. Natural materials used for road constructions being exhaustible in nature, its quantities are declining gradually. Also, cost of extracting good quality of natural material is increasing. Concerned about this, the scientists are looking for alternative materials for highway construction and for ways to improve the performance of asphalt pavements. Bottom ash is one of the alternative material. The combination of bottom ash with limestone aggregate and natural sand would seem to offer improvement to the overall performance of a bituminous paving mixture with respect to skid resistance and structural stability.The asphalt mixes containing bottom ash from different power plants have significantly different characteristics.

According to the Sunday observer on 3 October 2004, coal-fired electric power plant consumes approximately 2640 tons of coal per day in Sri Lanka. This consumption results in the production of more than 220 tons of coal ash, nearly180 tons of fly ash and 40 tons of bottom ash as waste at Norochcholai coal power plant in the Puttalam district in the north-western province. Coal ash consists fly ash and bottom ash. Bottom ash is the heavier ash that falls through the bottom of the furnace where it is collected in a hopper as shown in the Figure 1.1. It is classified as wet or dry bottom ash depending on the type of boiler used.

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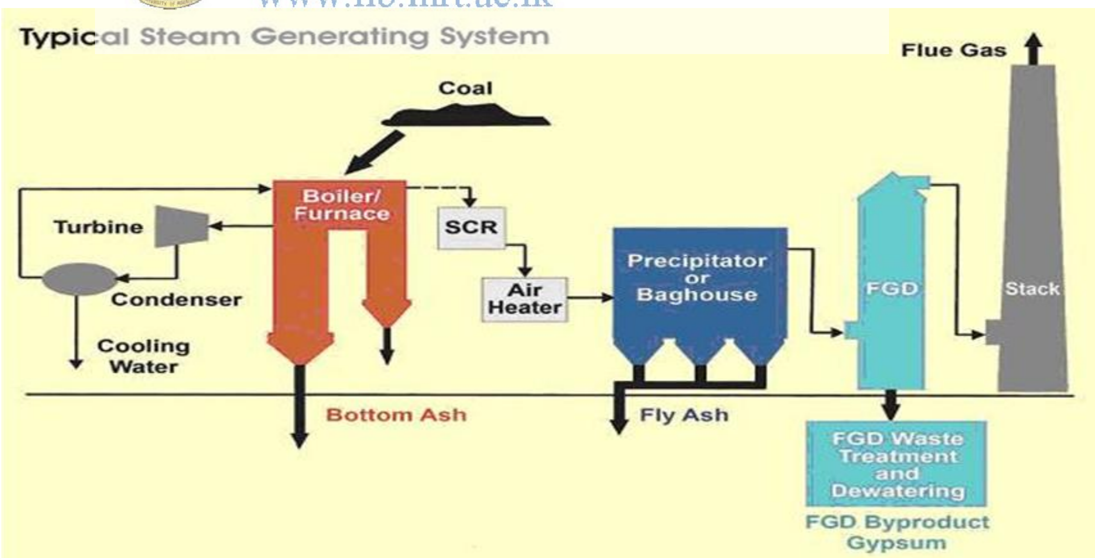


Figure 1.1 Typical steam generating system (Source: rmrc.wisc.edu)

As the consumption of coal by power plants increases, so does the production of coal ash. Disposal of unused coal ash is costly and places a considerable burden on the power industry. In addition, this would be a major environmental problem in future.

Dumping of ash is a major activity in this power plant where the land is very fertile and the fresh water layer is very little and only about 5 feet deep. Dumping of bottom ash in the land fillings and the seepage to the water table will cause severe hardships to agriculture and to ground water. So, removal of bottom ash is a major problem. If these wastes can be utilized in an efficient manner in highway construction, the pollution and disposal problems may be partly reduced.

## 1.2 Objectives

The main objective of the study was finding an alternative economical material for hot mix asphalt concrete in Sri Lanka. Under this, the research was focused to find the feasibility of usage of bottom ash, its characteristic in surface layers and how it enhances the HMA properties.

The other objective was to find an environmental friendly solution for the waste product of coal power plant that may be a huge environmental problem in future, while providing economical savings to the country.

## 1.3 Scope of the Study

- Study the performance of asphalt mix with bottom ash
- Determine the economical mix proportion and the optimum binder content for both wearing course and binder course while maintaining the standards and specifications
- Determine the cost saving percentage for bottom ash blended asphalt mix.
- Find the feasibility of usage of bottom ash in hot mix asphalt concrete in Sri Lanka.
- Provide environmental friendly solution for coal power plant's waste material.

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## 1.4 Scope of the Report

Chapter 1 describes the general background and the scope of the study. Chapter 2 of this report is about literacies of bottom ash and its properties, its usage in road construction, mix design procedures, laboratory testing as well as performance of design properties. Chapter 3 includes discussion of the methodology used, the experimental investigation of chemical, physical and mechanical properties of bottom ash. Chapter 4 describes the Marshallmix design for surface layers and includes the bitumen and aggregate properties. Chapter 5 describes the economical comparison of bottom ash usage, its feasibility and the results with the similar study. Finally, Chapter 6 summarizes the research performed, presents conclusions, and offers recommendations for further research.

# CHAPTER 2
# LITERATURE REVIEW

The literature review on bottom ash and its properties, its usage in road construction, mix design procedures, laboratory performance testing and performance of design properties were done under this project.

## 2.1 Bottom ash usage in Road construction

Bottom ash have been used with considerable success as fine aggregates in asphalt paving mixtures for at least the past 25 years in different sections of the United States. The American Coal Ash Association [1983] recently reported that during 1996 more than 75,000 metric tons of boiler slag and nearly 14,400 metric tons of bottom ash were used in asphalt paving.

As demonstrated, [Federal highway administration,2012] wet bottom ash has been used mainly in hot mix wearing surfaces, where it has been found to enhance skid resistance and to a lesser extent, in surface treatment or seal coat applications. A 1994 survey of all 50 state transportation agencies indicated that Arkansas, Missouri, Texas, West Virginia, and Wyoming states have made some recent use of bottom ash as an aggregate in asphalt paving on state roadways. Boiler slag (wet bottom ash) was first used in asphalt paving many years ago in Hammond, Indiana, where on an experimental basis, it was blended with conventional aggregate to help solve the problem of aggregate polishing. Also it has been used as an aggregate in hot mix asphalt paving in a number of cities such as Cincinnati and Columbus, Ohio, as well as in Tampa, Florida. Also, 10,000 tons of wet bottom ash were used to construct the wearing surface and shoulders of a portion of Interstate Route 94 near the Detroit Airport. This section of roadway was placed during the late 1970's and reportedly performed well into the mid 1980's. Further, it has been shown that, wet bottom ash (Boiler slag) has been used more frequently in hot mix asphalt than dry bottom ash because of its hard, durable particles and resistance to surface wear [Federal highway administration, 2012].

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Wyoming power plants consumed nearly 24 million tons of coal each year and the successful use of bottom ash in asphalt pavements in Wyoming has been provided significant economic savings. According to information given to the Wyoming Department of Environmental Quality by Wyodak power plant officials, there are several potential highway-related uses for bottom ash: Road Traction Agent, Road Surface Material, Hot Mix Asphalt Additive, Road Base and Structural Fill. It has been stated there are several states that currently allow bottom ash to be used as a Highway Material in USA. Those are Alaska Colorado, Arkansas Georgia, Indiana Illinois, Kentucky Iowa, New York Michigan, Ohio Minnesota, Texas Missouri, Virginia Montana, West Virginia Nebraska, New Jersey, New Mexico, North Dakota, Oklahoma, Oregon, Utah and Washington [Ksaibati & Stephen, 1999].

According to Hunsucker [1992] Kentucky is another state that has experimented with the use of bottom ash asphalt mixes. In a research project performed by the Kentucky

Transportation Centre, a one-mile experimental asphalt pavement overlay was placed in 1987. Forty percent of the aggregate used in the asphalt mix for this experiment was bottom ash. The optimum asphalt content was 8.5 percent.

The large quantity of aggregate used in HMA has put a strain on the supply of high-quality naturally occurring aggregate materials and has directed the attention of some research to searching for more innovative materials [Lovell, Ke, Huang, &Lovell, 1991]. Disposing of coal ash as a waste product is costly, puts a strain on limited landfill space, and may pose environmental problems. If productive use of ash becomes more common, this disposal problem may be solved [Lovell et.al, 1991].

West Virginia was one of the first states to use bottom ash in asphalt mixes. According to an article published in 1976 by the Asphalt Institute the West Virginia Department of Highways regards coal ash as aggregate that can be used in asphalt mixes. From 1971 to 1976 West Virginia paved more than 200 miles of low-volume roads with a mixture of bottom ash and emulsified asphalt cement [Asphalt Institute (AI), 1995].

## 2.2 Bottom ash properties and laboratory tests

A review of recent research done by Ksaibati and Stephen [1999] on bottom ash, it has the capability to improve asphalt pavement performance when used to replace a portion of the aggregate in asphalt mixes. Table 2.1 shows some of the engineering properties of bottom ash (wet and dry) from power plants in West Virginia [Federal highway administration, 2012].

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Table 2.1 Engineering properties of bottom ash from USA power plants

| Power Plant Source | Boiler Type | Bulk Sp. Gravity | % Water Absorption | L.A. Abrasion | MgSO4 Soundness | Friable Particles |
|---|---|---|---|---|---|---|
| Fort Martin | Dry bottom | 2.31 | 2.0 | 40 | 6 | Yes |
| Mitchell | Dry bottom | 2.68 | 0.8 | 37 | 10 | None |
| Hatfield | Dry bottom | 2.39 | 1.7 | 39 | - | Yes |
| Harrison | Dry bottom | 2.66 | 1.0 | 38 | - | Some |
| Kammer | Wet bottom | 2.76 | 0.3 | 37 | 10 | None |
| Willow Island | Wet bottom | 2.72 | 0.3 | 33 | 15M | None |
| Limestone Sand | Wet bottom | 2.65 | 1.1 | - | - | - |

The American Association of State Highway and Transportation Officials (AASHTO) [1991] stated that the performance of an asphalt mix relies heavily on the selection of the appropriate aggregate. When considering an aggregate for potential use in a mix, it is important to determine whether it possesses the desired characteristics.

Further, Roberts, Kandhal, Brown, Lee, & Kennedy [1991] stated aggregates used in HMA normally are required to have a hard, strong, and durable structure that is cubical in shape with low porosity. Several different tests may be used to determine these properties: the Los Angeles abrasion, sulfate soundness, sand equivalent, deleterious substances, crushed face count, polishing, flat elongated particles, specific gravity, and stripping tests.

AI [1995] described, asphalt cement is viscoelastic, meaning it displays viscose and elastic properties. At room temperature, asphalt cement is a semisolid material displaying elastic behavior. However, once heated it becomes more like a viscous fluid and can easily be mixed with aggregate to make HMA. Also, Asphalt cement is a durable material that displays excellent adhesive and waterproofing properties. It also is highly resistant to reactions with most acids, alkalies, and salts.

According to Ahmed, Imtiaz, & Lovell [1992], laboratory research has been conductedat Purdue University on the usage of bottom ash as a highway material. This research concluded bottom ash is a potentially corrosive material.

It is necessary to know physical properties and chemical composition of bottom ash. These properties are vary depending on the type, source, and fineness of the parent fuel, as well as the operating conditions of the power plant. Typical properties of wet and dry bottom ashare shown in Table 2.2 [Recycled material resource center].

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Table 2.2 Typical physical properties of bottom ash

| Property | Dry Bottom Ash | Wet bottom Ash (Boiler Slag) |
|---|---|---|
| Specific Gravity | 2.1 -2.7 | 2.3 - 2.9 |
| Dry Unit Weight | 7.07 - 15.72 $kN/m^3$ | 7.43 - 14.15 $kN/m^3$ |
| Plasticity | None | None |
| Absorption | 0.8 - 2.0% | 0.3 - 1.1% |

The chemical composition of bottom ash particles is controlled by the source of the coal and not by the type of furnace. Coal ash is composed primarily of silica ($SiO_2$), ferric oxide ($Fe_2O_3$), and alumina ($Al_2O_3$), with smaller quantities of calcium oxide (CaO), potassium oxide ($K_2O$), sodium oxide ($Na_2O$), magnesium oxide (MgO), titanium oxide ($TiO_2$), phosphorous pentoxide ($P_2O_5$), and sulfur trioxide ($SO_3$). In bituminous coal ash, the three major components ($SiO_2$, $Fe_2O_3$, and $Al_2O_3$) account for about 90 percent of the total components, whereas lignite and subbituminous coal ashes have relatively high percentages of CaO, MgO, and $SO_3$. Due to salt content and low pH, bottom ash may potentially be corrosive. When using bottom ash in an embankment, backfill, sub base, or even in a base course, the ash may come in contact with metal structures and cause corrosion [Recycled material resource center].

When consider bottom as a highway material, it is very important to know its mechanical properties. Table 2.3 shows the typical mechanical properties of bottom ash [Recycled material resource center].

Table 2.3 Typical mechanical properties of bottom ash

| Property | Bottom Ash | Boiler Slag |
|---|---|---|
| Maximum Dry Density $kN/m^3$ ($lb/ft^3$ ) | 11.79 - 15.72 (75 - 100) | 12.89 - 16.04 (82 - 102) |
| Optimum Moisture Content, % | Usually <20 12 - 24 range | 8 - 20 |
| Los Angeles Abrasion Loss % | 30 - 50 | 24 - 48 |
| Sodium Sulfate Soundness Loss % | 1.5 - 10 | 1 - 9 |
| Internal Friction Angle (drained) | 38 - 42° 32 - 45° (<9.5 mm size) | 38 - 42° 36 - 46° (<9.5 mm size) |
| California Bearing Ratio (CBR) % | 21 - 110 | 40 - 70 |
| Resilient Modulus ($M_R$) regression coefficients | $K_1$ = 5 - 12 MPa | |
| | $K_2$ = 0.52 | |
| Hydraulic Conductivity cm/sec | 1 - $10^{-3}$ | $10^{-1}$ - $10^{-3}$ |

The maximum dry density values of bottom ash are usually from 10 to 25 percent lower than that of naturally occurring granular materials. Moreover, the compaction curves of bottom ash generally have a flat shape, indicating that the material is insensitive to water content variations [Recycled material resource center].

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## 2.3 Bottom ash handling and storage

Bottom ash can be handled and stored or stockpiled using the same methods and equipment that are normally used for handling and storage of conventional aggregates in the plant [Federal highway administration, 2012].

Screening of oversized particles and blending with other aggregates will typically be required to use bottom ash in paving applications. Pyrites that may be present in the bottom ash should also be removed prior to use. According to the Recycled material resource center pyrites (iron sulfide) are volumetrically unstable, expansive, and produce a reddish stain when exposed to water over an extended time period. Technologies exist for processing bottom ash that can provide a cost-effective method to remove impurities, then bottom ash meets product quality targets.

## 2.4 Mixing, Placing and Compacting

As demonstrated in [Federal highway administration, 2012] the best use of wet bottom ash is as a partial replacement for the sand fraction of hot mix base and surface course mixtures. The type of aggregate used and the relative proportions of ash and aggregate have a significant influence on the properties of the paving mixture.

The same methods and equipment used for mixing, placing and compacting conventional pavements are applicable to asphalt pavements which contains bottom ash [Federal highway administration, 2012]. Compaction of asphalt mixes during field construction and in the laboratory indicate that asphalt mixes containing bottom ash require less compactive effort to achieve their desired optimum densities than the control asphalt mixes [Ksaibati & Stephen, 1999].

## 2.5 Performance of design properties

As [Federal highway administration,2012] mixes blended with rounded siliceous aggregates, such as uncrushed river sand, result in lower quality mixtures than blends containing crushed stone, which possess more desirable angularity and surface texture. Blending crushed stone aggregates with bottom ash is recommended because most bottom ash lack micro-texture, which increases the ability of aggregate to retain its asphalt coating and to provide skid resistance. Therefore, Rounded river sands should be avoided.

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According to the research done by Ksaibati and Stephen [1999], the Marshall mix design results indicated that asphalt mixes containing bottom ash have higher optimum asphalt contents than standard asphalt mixes. Also, the asphalt mixes containing bottom ash from different power plants had significantly different low temperature cracking and high temperature rutting characteristics.

Hunsucker's [1992] research showed that the combination of bottom ash with other aggregates in asphalt mixes appeared to improve the skid resistance of asphalt pavements. Bottom ash is a porous material and increases the requirement of asphalt cement and increases the cost of the asphalt mix. However, Hunsucker [1992] states that with the success of his experiment, it is possible that the unit price of asphalt mixes containing bottom ash will decrease to the point that will make them an economically viable alternative.

The additive used to modify an asphalt mix depends on the desired performance improvement. Miller stated there are several different additives currently being studied to improve the performance of asphalt mixes. Some of these additives include, rubber, plastic, fiber, oil, lime, Portland cement, fly ash, and bottom ash [Miller, 1995].

The Lafarge Corporation reports that bottom ash has a large surface area and rough texture that give it excellent adhesion capabilities and improves the skid resistance of pavements. Bottom ash also is a porous material that requires large amounts of asphalt cement. This improves cohesion of the aggregate and provides a more durable pavement [Lafarge Cooperation, 1997].

Research on the use of bottom ash in pavement construction also was performed by Ormsby and Fohs [1990]. They have found that, as the ash content in an asphalt mix is increased, the optimum asphalt content increases, the mix density decreases, and the air voids and voids in the mineral aggregate increases. The stability of asphalt mixes decreases up to approximately 30 percent. Asphalt mixes containing bottom ash have a lower resilient modulus and approximately the same Poisson ratios as standard mixes. Further, the fatigue life and fracture toughness of bottom ash asphalt mixes are higher than standard mixes. In addition, rutting and plastic deformation also are increased. Asphalt mixes containing bottom ash have a substantial resistance to environmental conditioning and damage caused by moisture [Ormsby & Fohs, 1990].

As Peurifoy, Ledbetter and Schexnayder [1996] one of an important characteristic of aggregate in an asphalt mix is its gradation. If a poor gradation is used, the asphalt mix may not possess the stability or shear strength needed to withstand construction or traffic loading. Anderson, Usmen, & Moulton [1976] concluded that the recommended percentage of wet bottom ash (boiler slag) should be less than 50 percent to maintain paving mixture stability since, wet bottom ash is typically poorly-graded sand-sized material.

## 2.6 Mix design methods

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Conventional AASHTO pavement structural design methods are appropriate for asphalt pavements incorporating bottom ash/boiler slag in the mix [Federal highway administration, 2012]. Both Marshal method [Ksaibati & Stephen, 1999] and super-pave method [Ksaibati & Huntington, 2004] are appropriate for HMA mix design.

According to the Lafarge Corporation, The Texas Department of Transportation also has experimented with asphalt mixes containing bottom ash. The asphalt mixes used in Texas was hot asphalt cement. In 1986, the Texas Department of Transportation Paris District constructed a fourteen mile pavement test section on Interstate 30. Nine years after its construction, there had been no apparent failures due to mixture characteristics [Lafarge Cooperation, 1997].

# CHPTER 3

## EXPERIMENTAL INVESTIGATION OF BOTTOM ASH

### 3.1 Methodology

To propose an economical mix proportion for flexible pavements based on bottom ash properties following methodology was adopted.

Initially, literacies was done to find the way of bottom ash produce, usage and application of bottom ash in other countries. Further study was done to identify the characteristic of bottom ash depending on the boiler type, chemical composition, physical and mechanical properties and so on.

Secondly, bottom ash samples were collected from Norochcholi coal power plant and the experimental investigation of Bottom ash was done to determine, physical and chemical properties of Norochcholai bottom ash particles, because depending upon the source, bottom ashes can have different physical and chemical properties.

Sieve analysis was done according to the ASTM standard to determine the particle size distribution of bottom ash, quarry dust, 12.5mm and 19mm aggregates. Then the specific gravities were determined for all aggregates. According to ASTM standards, Loss Angeles Abrasion test was performed to check whether bottom ash is durable enough for pavement construction. Also, Bottom ash's weathering resistance characteristic was determined using the $MgSO_4$ soundness test and then water absorption test was done for absorption quality. Then properties of bitumen (60/70) were determined according to the ASTM standards. [American Society for Testing and Materials (ASTM), 1994]. AIV test and FI tests were done for course aggregates according to British Standards.

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Thirdly, suitable mix proportion for bottom ash was selected considering combined gradation given in SSCM table 506-1 for both binder and wearing surface layers.

Then, trial mixes were prepared with different mix proportions of bottom ash and Marshall tests were done to find the variation of design characteristics such as flow value, VIM, VMA stability and optimum bitumen content with bottom ash replacement. After selecting appropriate bottom ash percentage for binder course and wearing course Mix designs were carried.

Finally, economical comparison of bottom ash blended hot mix asphalt concrete with conventional hot mix asphalt concrete was done to identify the economic feasibility of usage of bottom ash in hot mix asphalt concrete in Sri Lanka. Also, availability of material was consider to be feasible the bottom ash supply.

### 3.2 Chemical Composition of bottom ash

Bottom Ash is a waste material from coal burning power plants. It is the slag which builds up on the heat-absorbing surfaces of the furnace, and which subsequently falls to the bottom of the furnace and collected in an ash hopper. The bottom ash is categorized as dry bottom ash or wet bottom ash depending upon the boiler type used. The ash which is in solid state at the furnace bottom is called dry bottom ash. The ash which is in molten state when it falls in water is called either wet bottom ash or boiler slag.

Bottom ash consists of ash particles from natural minerals found in coal minerals such as quartz, feldspar, calcite and clay minerals as kaolinite and illite. The material is fine grained and similar to sand with a predominantly angular grain shape. It largely consists of aluminium silicate compounds [Recycled material resource center].

### 3.3 Physical and Mechanical Properties of Bottom Ash

With the advent of performance-based tests, it was expected that the performances of the conventional as well as new materials can be tested on a same set-up and be compared.

Bottom ash collected from Norochcholai coal power plant was used as the source of bottom ash for this study. Coal imported from Indonesia and Australia is used in Norochchalai coal power plant and the boiler type is wet bottom type. Properties of bottom ash depends on the source of coal use in the power plant [Recycled material resource center].

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a) **Grading:** The grading is significant in asphalt concrete properties, pavement skid resistance, binder content and production cost. ASTM D1073 defines a fine aggregate in asphalt paving mixtures as an aggregate that passes the 9.5 mm sieve [ASTM, 1994]. Particle size distribution for bottom ash is shown in the Table 3.1 and Figure 3.1.

Table 3.1 Particle size distribution for bottom ash

| Sieve Size in mm | Bottom Ash Passing % |
|---|---|
| 28 | 100 |
| 20 | 100 |
| 10 | 100 |
| 5 | 100 |
| 2.36 | 98 |
| 1.18 | 89.7 |
| 0.600 | 81.7 |
| 0.300 | 72.4 |
| 0.150 | 50.5 |
| 0.075 | 17.7 |

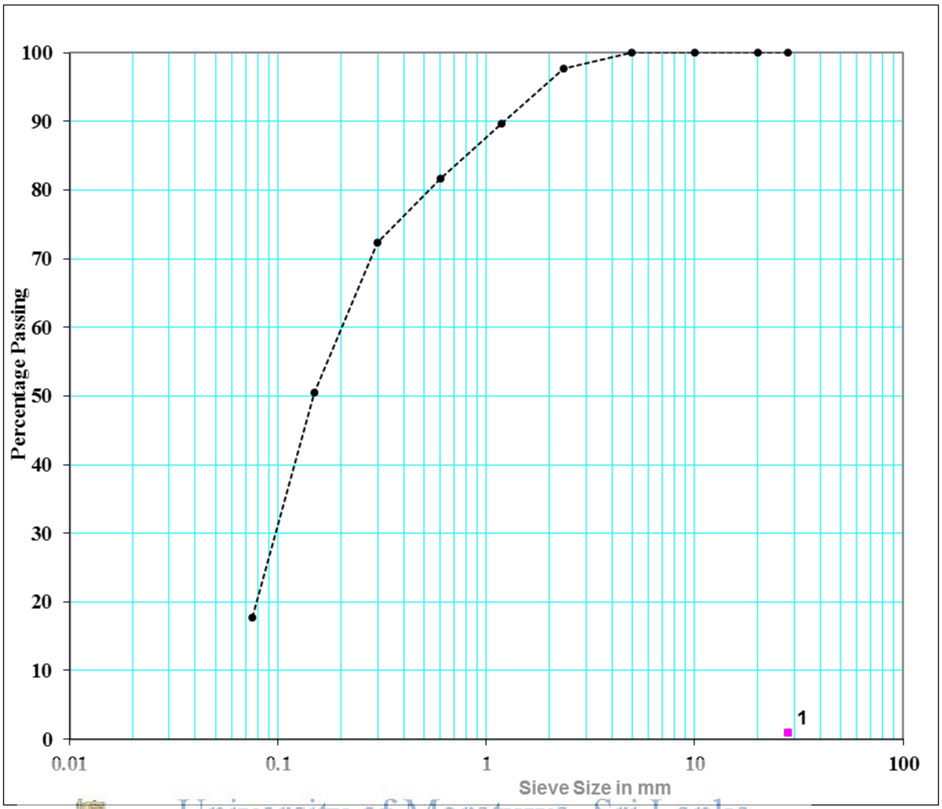


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Figure 3.1Grading of bottom ash

Wet bottom ash, the by-product of Norochcholai coal power plant is uniformly sized, and consists of hard, durable, glassy particles.

**(b) Specific gravity:** Specific gravity is a good indicator to measure the quality of a material. The specific gravity of bottom ash depends on the mineralogical composition of the material and the porosity of the particles. The test results are listed below for wet bottom ash, collected from Norochcholi coal power plant. Results are shown in Table 3.2 and can be concluded that wet bottom ash has nearly 35% lower specific gravity values than conventional aggregates.

Table 3.2Specific gravity of bottom ash

| Properties | Value |
|---|---|
| Relative density of Saturated and surface dried basis | 1.874 |
| Apparent relative density | 1.881 |
| Bulk specific gravity | 1.867 |

**(c) Durability:** The aggregates used in surface course of the highway pavements are subjected to wearing due to movement of traffic. When vehicles move on the road, the particles present between the pneumatic tiers and road surface cause abrasion of road aggregates. Therefore, the road aggregates should be hard enough to resist abrasion. Resistance to abrasion of aggregate is determined in laboratory by Los Angeles test machine. The principle of LAA test is to produce abrasive action by use of standard steel balls which when mixed with aggregates and rotated in a drum for specific number of revolutions also causes impact on aggregates. The percentage wear of the aggregates due to rubbing with steel balls is determined and is known as Los Angeles Abrasion Value and it should not be more than 40% for pavement construction [ASTM, 1994].

According to the Table 1 (ASTM-131-C) Grading D was selected for the sample and 5 kgs of sample dried in oven at 105° – 110°C. Then, 6 number of balls used as abrasive charge as per Table 2 and the machine was rotated up to 500 number of revolution. Finally the entire dust is sieved on 1.70 mm IS sieve and Los Angeles Abrasion Value was determined.

LAAV for wet bottom ash sample was determined as 30%.

**(d) $MgSO_4$Soundness:** Aggregates must be resistant to breakdown and disintegration from weathering or they may break apart and cause premature pavement distress. Soundness test was performed to measure the weathering resistance characteristic of bottom ash. Soundness values are generally found to be within ASTM D1073 weight loss specifications of not more than 15 % after five cycles when magnesium sulphate is used [ASTM, 1994].

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$MgSO_4$ Soundness for wet bottom ash sample was 10%

**(e) Water absorption***:* Water absorption is also one of the key performance indicators for bottom ash. Water absorption of bottom ash as a percentage of dry mass is given below.

Water absorption for wet bottom Ash - 0.41 %

The absorption rates of bottom ash is lower than same of quarry dust (0.62%). Low water absorption rate is suitable for asphalt concrete. Aggregates used to produce HMA are dried before blending with asphalt cement. Excessive moisture in the aggregates reduces the production rate of paving material due to the additional drying time required. Bottom ash is relatively easy to dewater, should be stockpiled and allowed to drain to a surface dry condition which is more economical [Federal highway administration, 2012].

## 3.4 Selecting Suitable Mix Proportion for Bottom Ash

Bottom ash almost always requires blending with other aggregate sources to meet gradation specifications. Bottom ash may contain iron pyrites that causes to reduce the pavement strength. Because of this reason, no more than 30 percent of the aggregate in an asphalt pavement mix should be replaced with bottom ash [Federal highway administration, 2012].

The blend proportions of bottom ash and conventional aggregates was decided mainly by the particle size distribution of the materials and the requirements of the gradation specifications as in Standard specifications for construction and maintenance of roads and bridges (SSCM), [2008] Table 506-1.

### (i) Wearing course

Aggregate blending percentages for wearing course are shown in Table 3.3 and 3.4 for both 25% of bottom ash blended mix and conventional mix respectively. Figure 3.2 and 3.3 are shown the selected combined gradation is within the specification limits according to SSCM [2008] Standards.

Table 3.3 Combined gradation for wearing course asphalt mix with 25% bottom ash

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| Percentage Passing | | | | | Blending Percentage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sieve Size in mm** | **Q/Dust Hot Bin # 1** | **5-14 mm Hot Bin # 2** | **25-14 mm Hot Bin # 3** | **Bott Ash Hot Bin # 4** | **No. 1 38%** | **No. 2 21%** | **No. 3 16%** | **No. 4 25%** | **Sieve Size in mm** | **Spec Limit Lower** | **Spec Limit Upper** | **Combined Grading** |
| 28 | 100 | 100 | 100 | 100 | 38 | 21 | 16.0 | 25.0 | 28 | 100 | 100 | 100 |
| 20 | 100 | 100 | 95 | 100 | 38 | 21 | 15.2 | 25.0 | 20 | 85 | 100 | 99 |
| 10 | 100 | 82.2 | 7.4 | 100 | 38 | 17.3 | 1.2 | 25.0 | 10 | 66 | 94 | 81 |
| 5 | 97.8 | 18 | 1.3 | 100 | 37.2 | 3.8 | 0.2 | 25.0 | 5 | 46 | 74 | 66 |
| 2.36 | 79.5 | 1.2 | 0 | 97.7 | 30.2 | 0.3 | 0.0 | 24.4 | 2.36 | 35 | 58 | 55 |
| 1.18 | 61.3 | 0 | 0 | 89.7 | 23.3 | 0.0 | 0.0 | 22.4 | 1.18 | 26 | 48 | 46 |
| 0.600 | 46.4 | 0 | 0 | 81.7 | 17.6 | 0.0 | 0.0 | 20.4 | 0.600 | 18 | 38 | 33 |
| 0.300 | 26.5 | 0 | 0 | 72.4 | 10.1 | 0.0 | 0.0 | 18.1 | 0.300 | 11 | 28 | 25 |
| 0.150 | 16.5 | 0 | 0 | 50.5 | 6.3 | 0.0 | 0.0 | 12.6 | 0.150 | 7 | 20 | 19 |
| 0.075 | 7.3 | 0 | 0 | 17.7 | 2.8 | 0.0 | 0.0 | 4.4 | 0.075 | 3 | 12 | 7 |

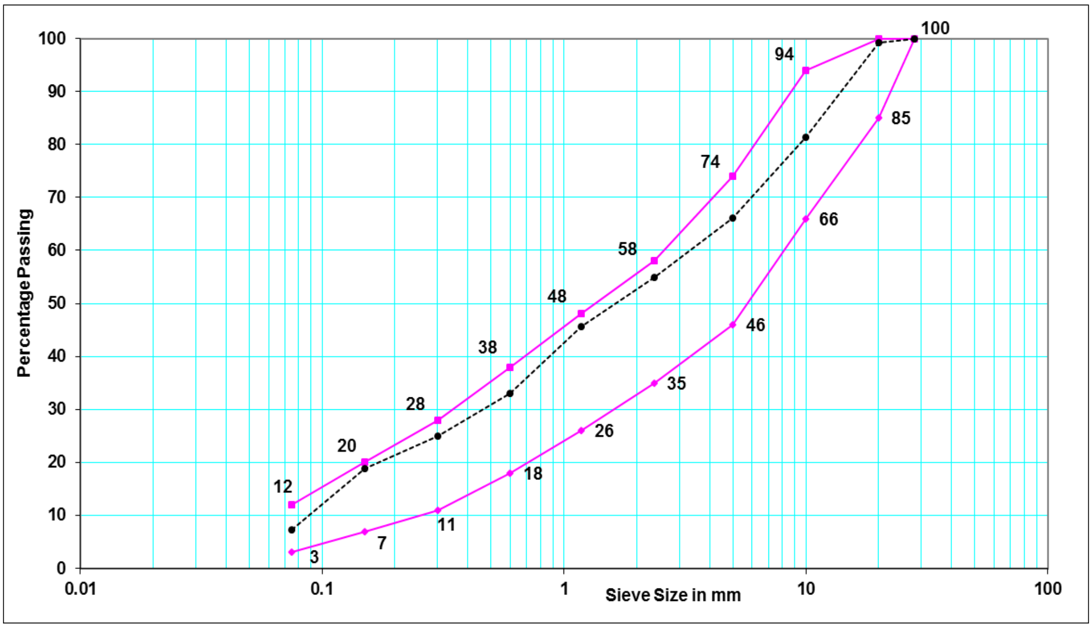


Figure 3.2- Combined Gradation with 25 % bottom ash for Wearing Course (type 1) according to SSCM Table 506-1

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Table 3.4 Combined gradation for wearing course asphalt mix for conventional mix

| Percentage Passing | | | | Blending Percentage | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sieve Size in mm** | **Q/Dust Hot Bin # 1** | **5 -14 mm Hot Bin # 2** | **25 - 14 mm Hot Bin # 3** | **No. 1 55%** | **No. 2 30%** | **No. 3 15%** | **Sieve Size in mm** | **Spec Limit Lower** | **Spec Limit Upper** | **Combined Grading** |
| 28 | 100 | 100 | 100 | 55 | 30 | 15.0 | 28 | 100 | 100 | 100 |
| 20 | 100 | 100 | 95 | 55 | 30 | 14.3 | 20 | 85 | 100 | 99 |
| 10 | 100 | 82.2 | 7.4 | 55 | 24.7 | 1.1 | 10 | 66 | 94 | 81 |
| 5 | 97.8 | 18 | 1.3 | 53.8 | 5.4 | 0.2 | 5 | 46 | 74 | 59 |
| 2.36 | 79.5 | 1.2 | 0 | 43.7 | 0.4 | 0.0 | 2.36 | 35 | 58 | 44 |
| 1.18 | 61.3 | 0 | 0 | 33.7 | 0.0 | 0.0 | 1.18 | 26 | 48 | 34 |
| 0.600 | 46.4 | 0 | 0 | 25.5 | 0.0 | 0.0 | 0.600 | 18 | 38 | 26 |
| 0.300 | 26.5 | 0 | 0 | 14.6 | 0.0 | 0.0 | 0.300 | 11 | 28 | 15 |
| 0.150 | 16.5 | 0 | 0 | 9.1 | 0.0 | 0.0 | 0.150 | 7 | 20 | 9 |
| 0.075 | 7.3 | 0 | 0 | 4.0 | 0.0 | 0.0 | 0.075 | 3 | 12 | 4 |

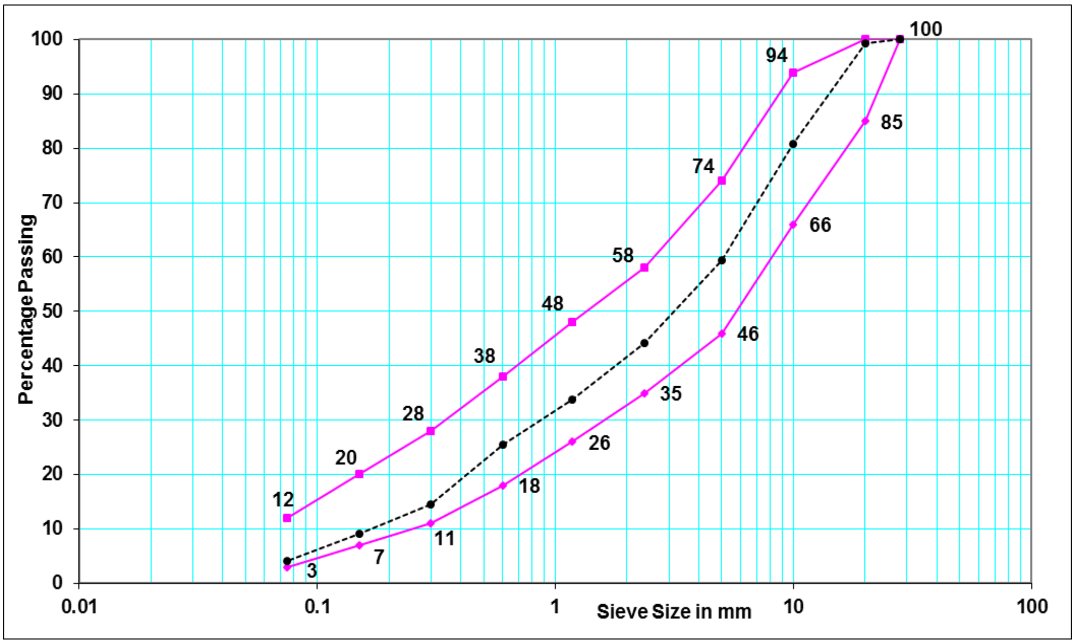


Figure 3.3- Combined gradationfor conventional wearing course (type 1) according to SSCM Table 506-1

**(ii) Binder course**

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Aggregate blending percentages for binder course are shown in Table 3.5 and 3.6 for both 16% of bottom ash blended mix and conventional mix respectively. Figure 3.4 and 3.5 are shown the selected combined gradation is within the specification limits for the same respectively.

Table 3.5 Combined gradation for binder course asphalt mix with 16% bottom ash

| Percentage Passing | | | | | Blending Percentage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sieve Size in mm | Q/Dust Hot Bin # 1 | 5-14 mm Hot Bin # 2 | 25-14 mm Hot Bin # 3 | Bott Ash Hot Bin # 4 | No. 1 27% | No. 2 29% | No. 3 28% | No. 4 16% | Sieve Size in mm | Spec Limit Lower | Spec Limit Upper | Combined Grading |
| 28 | 100 | 100 | 100 | 100 | 27 | 29 | 28.0 | 16.0 | 28 | 100 | 100 | 100 |
| 20 | 100 | 100 | 95 | 100 | 27 | 29 | 26.6 | 16.0 | 20 | 90 | 100 | 99 |
| 10 | 100 | 82.2 | 7.4 | 100 | 27 | 23.84 | 2.1 | 16.0 | 10 | 56 | 82 | 69 |
| 5 | 97.8 | 18 | 1.3 | 100 | 26.4 | 5.22 | 0.4 | 16.0 | 5 | 36 | 58 | 48 |
| 2.36 | 79.5 | 1.2 | 0 | 97.7 | 21.5 | 0.35 | 0.0 | 15.6 | 2.36 | 21 | 38 | 36 |
| 1.18 | 61.3 | 0 | 0 | 89.7 | 16.6 | 0 | 0.0 | 14.4 | 1.18 | 15 | 32 | 31 |
| 0.600 | 46.4 | 0 | 0 | 81.7 | 12.5 | 0.0 | 0.0 | 13.1 | 0.600 | 10 | 26 | 24 |
| 0.300 | 26.5 | 0 | 0 | 72.4 | 7.2 | 0.0 | 0.0 | 11.6 | 0.300 | 6 | 20 | 19 |
| 0.150 | 16.5 | 0 | 0 | 50.5 | 4.5 | 0.0 | 0.0 | 8.1 | 0.150 | 3 | 13 | 12 |
| 0.075 | 7.3 | 0 | 0 | 17.7 | 2.0 | 0.0 | 0.0 | 2.8 | 0.075 | 1 | 7 | 5 |

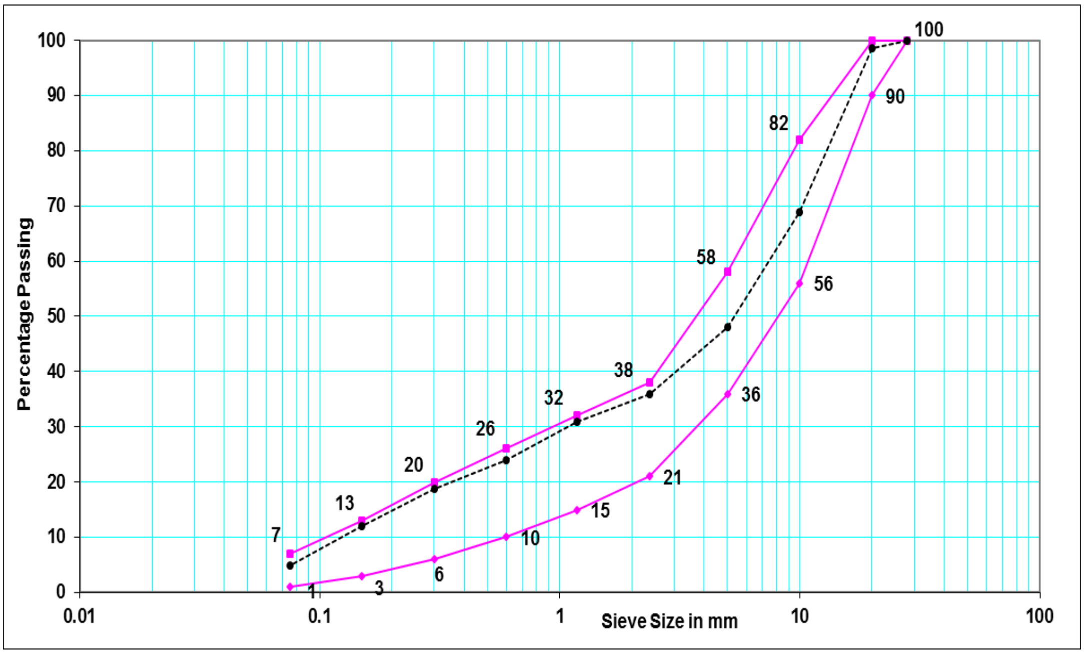


Figure 3.4- Combined gradation with 16 % bottom ash t for binder course according to SSCM Table 506-1

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Table 3.6 Combined gradation for binder course asphalt mix for conventional mix

| Percentage Passing | | | | Blending Percentage | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sieve Size in mm** | **Q/Dust Hot Bin # 1** | **5 -14 mm Hot Bin # 2** | **25 - 14 mm Hot Bin # 3** | **No. 1 40%** | **No. 2 30%** | **No. 3 30%** | **Sieve Size in mm** | **Spec Limit Lower** | **Spec Limit Upper** | **Combined Grading** |
| 28 | 100 | 100 | 100 | 40 | 30 | 30.0 | 28 | 100 | 100 | 100 |
| 20 | 100 | 100 | 95 | 40 | 30 | 28.5 | 20 | 90 | 100 | 99 |
| 10 | 100 | 82.2 | 7.4 | 40 | 24.7 | 2.2 | 10 | 56 | 82 | 67 |
| 5 | 97.8 | 18 | 1.3 | 39.1 | 5.4 | 0.4 | 5 | 36 | 58 | 45 |
| 2.36 | 79.5 | 1.2 | 0 | 31.8 | 0.4 | 0.0 | 2.36 | 21 | 38 | 32 |
| 1.18 | 61.3 | 0 | 0 | 24.5 | 0.0 | 0.0 | 1.18 | 15 | 32 | 25 |
| 0.600 | 46.4 | 0 | 0 | 18.6 | 0.0 | 0.0 | 0.600 | 10 | 26 | 19 |
| 0.300 | 26.5 | 0 | 0 | 10.6 | 0.0 | 0.0 | 0.300 | 6 | 20 | 11 |
| 0.150 | 16.5 | 0 | 0 | 6.6 | 0.0 | 0.0 | 0.150 | 3 | 13 | 7 |
| 0.075 | 7.3 | 0 | 0 | 2.9 | 0.0 | 0.0 | 0.075 | 1 | 7 | 3 |

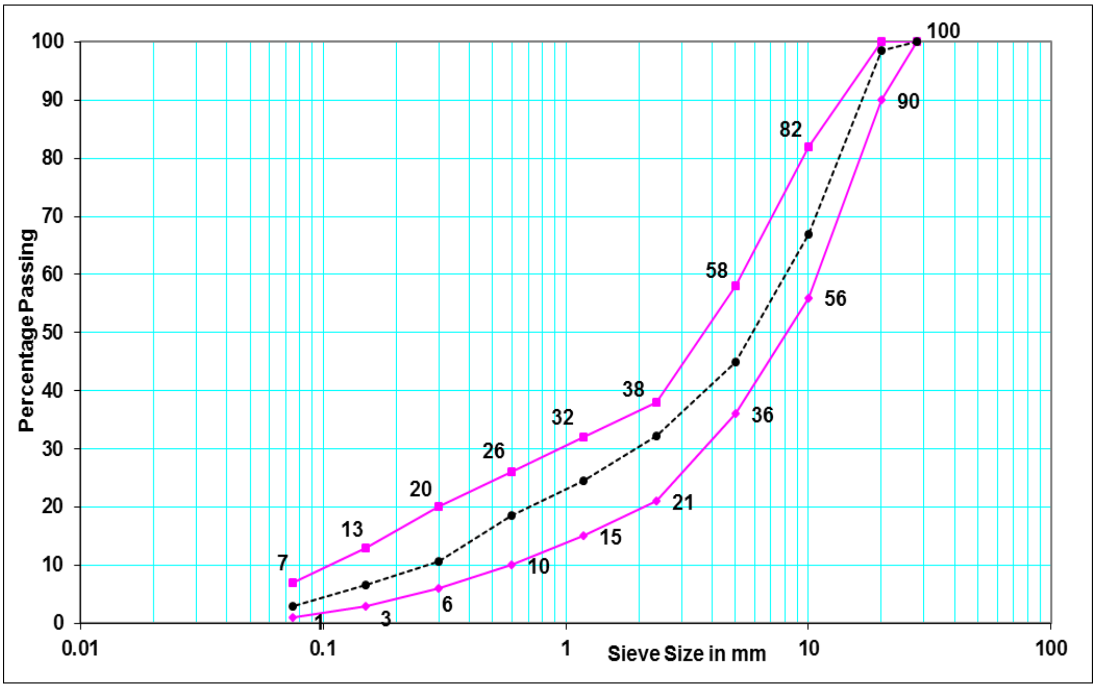


Figure 3.5- Combined gradation for conventional binder course according to SSCM Table 506-1

According to SSCM blending standard the required economical bottom ash proportion was about 16% for binder course and 25% for wearing course.

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For HMA manufacturing allowable tolerance limit within the specification bands must be provided to allow for inherent material and production variability. The manufacturer is expected to adhere quite closely to this Job Mix Formula gradation during production. Therefore, tolerance limits were decided with considering the Specification limits in Table 506-1 and the permissible variations from job mix formula in Table 506-3 in ICTAD specification standards [19].

Table 3.7 shows the allowable tolerance limits for wearing course with 25% bottom ash and figure 3.6 illustrates it graphically. According to the figure 3.6 upper limit tolerance is limited by the specification standard for combined grading. As the aim is to maximum the usage of bottom ash, combined grading was selected with providing small upper variation limit.

Table 3.7 Job mix formula & tolerance bands for wearing course with 25% bottom ash

| **Sieve Size in mm** | **Combined Grading %** | **With Allowable Tolerance** | |
|---|---|---|---|
| | | **Lower limit** | **Upper limit** |
| 28 | 100 | 100 | 100 |
| 20 | 99 | 91 | 100 |
| 10 | 81 | 74 | 88 |
| 5 | 66 | 59 | 73 |
| 2.36 | 55 | 49 | 58 |
| 1.18 | 46 | 40 | 48 |
| 0.600 | 33 | 28 | 38 |
| 0.300 | 25 | 20 | 28 |
| 0.150 | 19 | 15 | 20 |
| 0.075 | 7 | 6 | 9 |

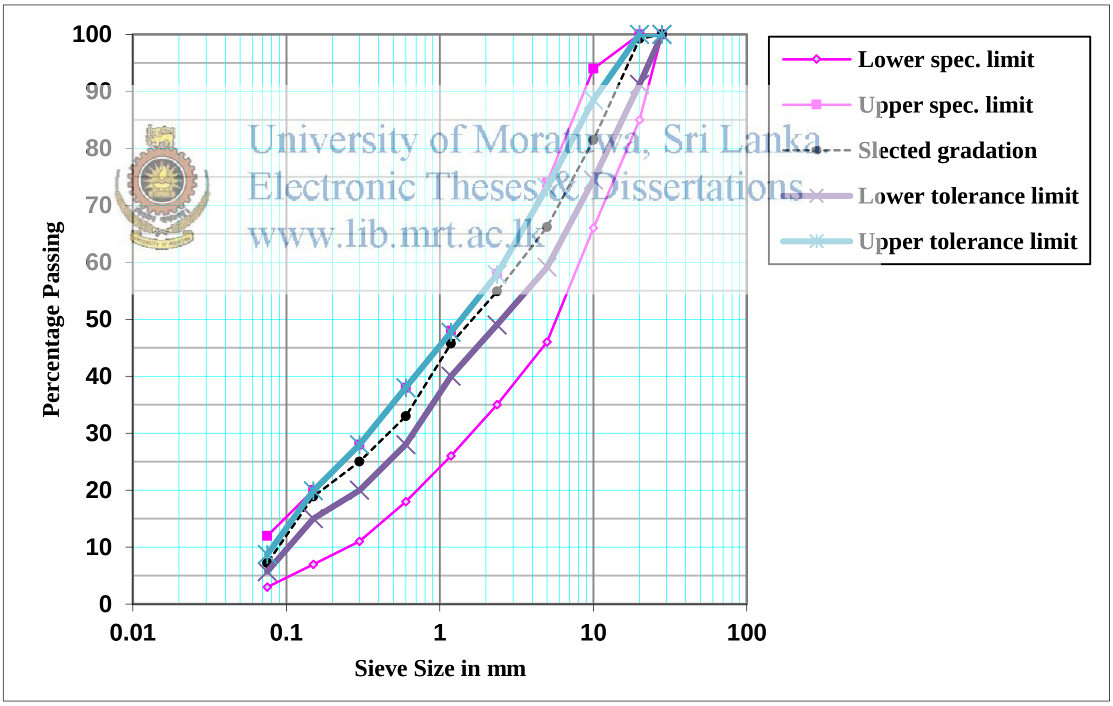

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Figure 3.6- Combined gradation with allowable tolerance limit for wearing course with 25% bottom ash

Also, Table 3.8 shows the allowable tolerance limits for binder course with 16% bottom ash and figure 3.7 graphically represents the combined gradation with allowable tolerance limit. According to the figure 3.7 lower part of the upper tolerance is limited by the specification standard for combined grading. As the aim is to maximum the usage of bottom ash, combined grading was selected with providing small upper variation limit.

Table 3.8 Job mix formula & tolerance bands for binder course with 16% bottom ash

| Sieve Size in mm | Combined Grading % | With Allowable Tolerance | |
|---|---|---|---|
| | | Lower limit | Upper limit |
| 28 | 100 | 100 | 100 |
| 20 | 99 | 91 | 100 |
| 10 | 69 | 62 | 76 |
| 5 | 48 | 41 | 55 |
| 2.36 | 36 | 30 | 38 |
| 1.18 | 31 | 25 | 32 |
| 0.600 | 24 | 19 | 26 |
| 0.300 | 19 | 14 | 20 |
| 0.150 | 12 | 8 | 13 |
| 0.075 | 5 | 3 | 6 |

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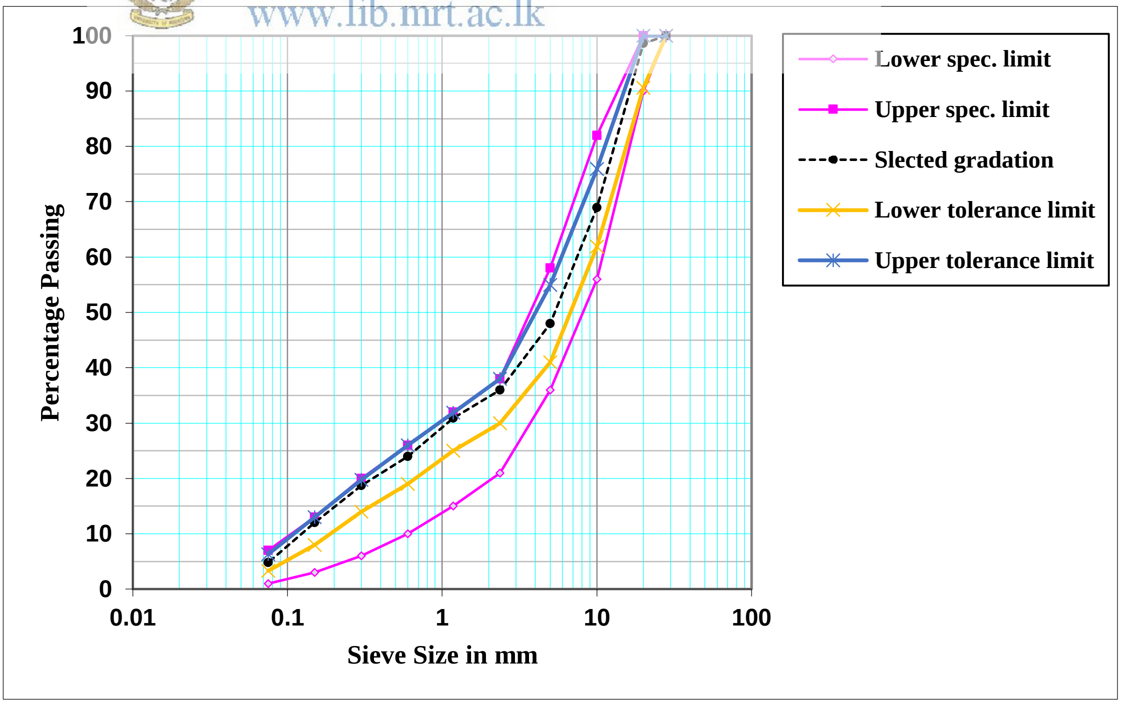


Figure 3.7- Combined gradation with allowable tolerance limit for binder course with 16% bottom ash

# CHPTER 4
# DEVELOPMENT OF MIX DESIGN

Mix design can be defined as the process of selecting and proportioning the constitutive materials of asphalt concrete to produce an economical mix, which has certain desirable properties such as strength, workability and durability. Conventional Marshall mix design method was used for asphalt pavements incorporating bottom ash HMA [Ksaibati & Stephen, 1999].

Normally asphalt roads are designed for both wearing course and binder course. Therefore the mix designs were done for both layers. Initially, properties of bitumen, 19 mm, 12.5 mm aggregates and quarry dust were determined.

## 4.1Properties of Bitumen

60/70 penetration grade bitumen was used as the binder material for all trial mixes and the properties of bitumen sample are shown in Table 4.1.

Table 4. 1 Properties of bitumen

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| Property | Test method | Test Results | Specification Limit | |
|---|---|---|---|---|
| | | | Min | Max |
| Penetration 25 $^0$C, 100g, 5s | ASTM D 5 - 86 | 65 | 60 | 70 |
| Flash point (Cleveland open cup) $^0$C | ASTM D 92 - 78 | 312 | 232 | |
| Softening Point $^0$C | ASTM D 36 - 86 | 49 | 48 | 56 |
| Loss on heating for 5 hrs at 163 $^0$C | | | | |
| (i) Loss by weight percent | ASTM D 6 - 80 | 0.05 | - | 1 |
| (i)Penetration after loss of heating test percent of its original value | ASTM D 5 - 86 | 93 | 75 | |
| Solubility in trichloroethylene % | ASTM D 2042 - 81 | 99.7 | 99 | |
| Specific Gravity at 25/25$^0$C | ASTM D 70 - 82 | 1.018 | 1.01 | 1.06 |
| Ductility 25$^0$C, 5cm/min., cm | ASTM D 113 - 86 | 126 | 100 | - |

## 4.2 Properties of Aggregates

Properties of 19 mm aggregates, 12.5 mm aggregates and quarry dust used for all trial mixes were tested and results are shown in Table 4.2.

Table 4.2 Properties of aggregates

| Test | Quarry dust | 12.5 mm | 19 mm | Test method |
|---|---|---|---|---|
| AIV | - | - | 24 | BS 812 |
| LAAV | - | - | 40 | ASTM C 131 |
| FI | - | 30 | 22 | BS 812 |
| Specific Gravity (Dry) | 2.832 | 2.75 | 2.794 | ASTM C 127-77 |
| Specific Gravity (App) | 2.834 | 2.797 | 2.809 | ASTM C 128-73 |

## 4.3 Marshall Mix Design

The Marshall Mix design properties of HMA containing wet bottom ash depend on amount of ash content.[Federal highway administration,2012].Initially, five number of HMA concrete sample mixes were prepared including control mix for each wearing and binder courses. Then, Marshall tests were carried out to find Stability, Flow value, VIM and VMA for mixes.

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Table 4.3 Variation of optimum bitumen content and the stability value with increase of bottom ash replacement percentage

for wearing course

| Sample No | Bottom ash replacement % | Optimum Bitumen Content | Stability Value (kN) |
|---|---|---|---|
| Control mix | 0 | 4.8 | 10.3 |
| 1 | 20 | 5.4 | 10.7 |
| 2 | 25 | 5.5 | 9.6 |
| 3 | 30 | 7.3 | 7.8 |
| 4 | 35 | 8.2 | 6.0 |

For binder course

| Sample No | Bottom ash replacement % | Optimum Bitumen Content | Stability Value (kN) |
|---|---|---|---|
| Control mix | 0 | 4.7 | 15.0 |
| 1 | 8 | 5.2 | 14.2 |
| 2 | 16 | 5.4 | 11.8 |
| 3 | 25 | 7.0 | 7.5 |
| 4 | 35 | 8.4 | 7.0 |

Optimum bitumen content was the main parameter that varies the economical savings of bottom ash usage, because other properties of mixes were not varied significantly with the control mix although the binder requirement increased as bottom ash replacement is increased. Optimum bitumen content and the stability values variation for both surface layers with increase of bottom ash replacement percentage can be clearly seen (Table 4.3).

Further, according to the sample number 3 and 4 results, when the bottom ash replacement percentage is increased the optimum bitumen content is also increased. The high percentage of bitumen content is not economically viable and caused to reduce the stability value. Stability of HMA mix has been decreased up to an ash content of 30% for wearing course and 16% for binder course and further ash replacement is not satisfied the specification requirement of "not less than 8 kN for stability".

As the suitable stability value and reasonable binder requirement Sample number 2 was selected for further studies for both wearing course and binder course layers.

### 4.3.1 Marshall test for wearing course

Samples were prepared with maximum replacement of 25% of bottom ash and conventional mix as the control mix and Marshall test was carried out to find the asphalt mix properties and the optimum bitumen content.

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To evaluate the economic feasibility of this project, mix design characteristics of the mix with conventional aggregates was compared with bottom ash blended aggregate mix properties. The Marshall test results for wearing course are given in Table 4.4.

Table 4.4 Marshall mix design properties for wearing course

| Property | Optimum Values | | Specification Limit (SSCM - Table 506 -2b) |
|---|---|---|---|
| | Control mix | Mix with 25% bottom ash | |
| Stability (KN) | 10.3 | 9.6 | Not less than 8.0 |
| Flow (0.25mm) | 12 | 12.5 | 8 to 16 |
| VIM (%) | 4.9 | 5.5 | 3 to 7 |
| VMA (%) | 15.9 | 16.3 | Not less than 13 for design VIM of 4% |
| Optimum Bitumen Content (weight %) | 4.8 | 5.5 | |
| Bulk Specific Gravity | 2.469 | 2.252 | |

Then the mixing percentages was calculated with considering bitumen weight and amount of material requirement for one metric ton (1000 kg).The material weights for 1 Mt for both conventional and bottom ash mixed HMA concrete are shown in the Tables 4.5 and 4.6 respectively.

Table 4.5 Material weights for one Mt of wearing course for conventional mix

| Type of Bin | HOT BIN # 1 ( 5 - 0 mm Agg.) | HOT BIN # 2 (14 - 5 mm Agg,) | HOT BIN # 3 ( 25- 10 mm Agg,) | Bitumen ( 60 -70 ) |
|---|---|---|---|---|
| Mix Proportion (By Weight of Mix) | 52.4% | 28.6% | 14.3% | 4.8% |
| Weight for the 1 Mt (kg) | 524 | 286 | 143 | 48 |

Table 4.6 Material weights for one Mt of wearing course for bottom ash blended mix

| Type of Bin | HOT BIN # 1 ( 5 - 0 mm Agg.) | HOT BIN # 2 (14 - 5 mm Agg,) | HOT BIN # 3 ( 25- 10 mm Agg,) | HOT BIN # 4 ( Bottom Ash) | Bitumen ( 60 -70 ) |
|---|---|---|---|---|---|
| Mix Proportion (By Weight of Mix) | 35.9% | 19.8% | 15.1% | 23.6% | 5.5% |
| Weight for 1 Mt (kg) | 359 | 198 | 151 | 236 | 55 |

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### 4.3.2 Marshall test for binder course

Samples were prepared with maximum replacement of 16% of bottom ash and conventional mix (control mix) for binder course. Then, Marshall tests were carried out to find design properties and optimum bitumen contents of the samples. According to the results Marshall mix design properties are given in Table 4.7.

Table 4.7 Marshall Mix design properties for binder course

| **Property** | **Optimum Values** | | **Specification Limit (SSCM - Table 506 -2a)** |
|---|---|---|---|
| | **Control mix** | **Mix with 16% bottom ash** | |
| Stability (KN) | 15 | 11.8 | Not less than 8.0 |
| Flow (0.25mm) | 10 | 13 | 8 to 16 |
| VIM (%) | 5.5 | 6.2 | 3 to 7 |
| VMA (%) | 15.1 | 16.5 | Min. 13 and max. 20 for design VIM of 4% |
| Optimum Bitumen Content (% weight) | 4.7 | 5.4 | |
| Bulk Specific Gravity | 2.581 | 2.342 | |

After that, the mixing percentages were calculated with considering bitumen weight and amount of material requirement for one Mt (1000 kg).The material weights for one metric ton for both conventional and bottom ash mixed HMA binder course are shown in the Tables 4.8 and 4.9 respectively.

Table 4.8 Material weights for one Mt of binder course for conventional mix

| Type of Bin | HOT BIN # 1 ( 5 - 0 mm Agg.) | HOT BIN # 2 (14 - 5 mm Agg,) | HOT BIN # 3 ( 25- 10 mm Agg,) | Bitumen ( 60 -70 ) |
|---|---|---|---|---|
| Mix Proportion (By Weight of Mix) | 38.1% | 28.6% | 28.6% | 4.7% |
| Weight for the one batch ( Kg ) | 381 | 286 | 286 | 47 |

Table 4.9 Material weights for one Mt of binder course for bottom ash blended mix

| Type of Bin | HOT BIN # 1 ( 5 - 0 mm Agg.) | HOT BIN # 2 (14 - 5 mm Agg,) | HOT BIN # 3 ( 25- 10 mm Agg,) | HOT BIN # 4 ( Bottom Ash,) | Bitumen ( 60 -70 ) |
|---|---|---|---|---|---|
| Mix Proportion (By Weight of Mix) | 25.5% | 27.4% | 26.5% | 15.2% | 5.4% |
| Weight for 1 Mt | 255 | 274 | 265 | 152 | 54 |

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# CHAPTER 5
# ECONOMIC FEASIBILTY OF BOTTOM ASH

## 5.1 Economical Comparison

Economical comparison was done for bottom ash blended hot mix asphalt concrete with conventional hot mix asphalt concrete for both binder and wearing surface layers. Current market prices and the Highway Rate of Schedule (HSR) of Road Development Authority were used for cost calculation of mixtures. Table 5.1 shows the summary of cost details used for the calculation. Only material and transport costs were considered.

Table 5.1 Cost details

| Mateiral | Price of 1 $m^3$ with 35km transport (Rs.) |
|---|---|
| Quarry dust | 2807.90 |
| 5-14 mmAgg. | 3137.22 |
| 10-25 mm Agg. | 3147.22 |
| Bitumen ( 60 -70 ) | 102.06 |

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If economical utilization of the bottom ash was to be achieved, it was thought to be essential to have a source of the waste material near the asphalt plant. As Norochcholai coal Power plant officials ready to supply the bottom ash materials to asphalt plants at no cost, the costs incurred for the mixture involved only mixing and placing costs which is same to the conventional mixing method.

Material weights for one Mt of wearing course with 20% bottom ash and binder course with 8% bottom ash were calculated as shown in table 5.2 and 5.3 respectively. Then costs were calculated and compared.

Table 5.2 Material weights for one Mt of wearing course for 20% bottom ash blended mix

| Type of Bin | HOT BIN # 1 ( 5 - 0 mm Agg.) | HOT BIN # 2 (14 - 5 mm Agg.) | HOT BIN # 3 ( 25- 10 mm Agg.) | HOT BIN # 4 ( Bottom Ash) | Bitumen ( 60 -70 ) |
|---|---|---|---|---|---|
| Mix Proportion (By Weight of Mix ) | 37.8% | 18.9% | 18.9% | 18.9% | 5.4% |
| Weight for 1 Mt (kg) | 378 | 189 | 189 | 189 | 54 |

Table 5.3 Material weights for one Mt of binder course for 8% bottom ash blended mix

| Type of Bin | HOT BIN # 1 ( 5 - 0 mm Agg.) | HOT BIN # 2 (14 - 5 mm Agg,) | HOT BIN # 3 ( 25- 10 mm Agg,) | HOT BIN # 4 ( Bottom Ash,) | Bitumen ( 60 -70 ) |
|---|---|---|---|---|---|
| Mix Proportion (By Weight of Mix | 28.4% | 29.4% | 29.4% | 7.6% | 5.2% |
| Weight for 1 Mt | 284 | 294 | 294 | 76 | 52 |

The costs and the saving percentages of usage of bottom ash are compared as shown in Table 5.4 and 5.5.

Table 5.4 Cost comparison with conventional mix for BA replacement in WC

| **Description** | **Control mix** | **With max % of botttom ash (25%)** | **With 20 % of botttom ash** |
|---|---|---|---|
| Cost per batch (1Mt) Rs. | 5812.44 | 6261.01 | 6212.06 |
| Weight per batch (kg) | 1000 | 1000 | 1000 |
| Bulk Specific Gravity | 2.469 | 2.252 | 2.283 |
| Let, Avg. design Thickness (mm) | 40 | 40 | 40 |
| Overlay area ($m^2$) | 10.13 | 11.10 | 10.95 |
| Cost per $m^2$ (Rs.) | 574.04 | 563.99 | 567.29 |
| **Saving percentage per 1 $m^2$** | | **1.75** | **1.18** |

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Wearing course mixes with 25% of bottom ash shows considerable savings, while less amount of ash replacement reduces the saving percentage per unit surface area.

Table 5.5 Cost comparison with conventional mix for BA replacement in BC

| **Description** | **Control mix** | **with max % of botttom ash (16%)** | **with 8 % of botttom ash** |
|---|---|---|---|
| Cost per batch (1Mt) Rs. | 5730.72 | 6270.68 | 6153.00 |
| Weight per batch (kg) | 1000 | 1000 | 1000 |
| Bulk Spesific Gravity | 2.581 | 2.342 | 2.423 |
| Let, Avg. design Thickness (mm) | 60 | 60 | 60 |
| Overlay area ($m^2$) | 6.46 | 7.12 | 6.88 |
| Cost per $m^2$ (Rs.) | 887.46 | 881.16 | 894.52 |
| **Saving percentage per 1 $m^2$** | | **0.71** | **-0.80** |

Binder course mixes with 16% of bottom ash shows some saving compared to the control mix. However, some bottom ash replacement percentages may not be economically viable.

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**5.2 Comparison of results with similar past study**

According to the study on performance of bottom ash asphalt mixes by Ksaibati and Huntington [1999], Wyoming bottom ash used for the study also was wet bottom ash. In their study, 15% aggregate replacement was done by bottom ash. According to their results asphalt contents for bottom ash mixes have been varied from 4.7% to 5.7% for limestone control mix and 5.5% to 6% for granite control mix. Moreover, 0.5% and 1% higher value than for the control mixes.

When compare the results gained from this study, bitumen content have been increased from 4.7% to 5.4% for 15 % aggregate replacement in binder course and from 4.8% to 5.5% for 25% aggregate replacement in wearing course. This is 0.7% higher value than for the control mixes. Those results are almost similar to the results of [18].

### 5.34 Bottom Ash Availability

To be feasible the bottom ash usage in road construction, it is necessary to check the availability and the consistency of the supply without any shortage. When power plant runs in full load (300 Mw) total bottom ash production is approximately 2.5 tons/h. Table 5.6 describes the overlaying road distance per day that can be done using the current rate of bottom ash production.

Table 5.6 Possible overlaying road distance per day as bottom ash production rate

| Description | Wearing course | Binder course |
| --- | --- | --- |
| BA requirement for 1 Mt (kg) | 236 | 152 |
| BA blended Asphalt production (Mt) per hr | 10.6 | 16.4 |
| Bulk specific gravity of BA blended mix | 2.252 | 2.342 |
| Assume the Road width is 5 m | | |
| Let avg. design Thickness (mm) | 40 | 60 |
| Overlaying kms per hr | 23.5 | 23 |
| When the plant operates 8 hrs per day | | |
| Overlaying kms (5m width) per Day | 188 | 184 |

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When consider the above figures, availability of bottom ash is at the satisfactory level for overlaying of nearly 180 km surface layer per day when the plant operates in full load. Further, if the plant operates at 50% and 25 % of its efficiency, nearly 90 kms and 45 kms of overlay distances are possible per day respectively. Therefore, it can be concluded that the bottom ash production per day is sufficient for considerable length of surface layer construction per day.

# CHAPTER 6
# CONCLUSION AND RECOMMENDATION

## 6.1 Conclusions

The performance of this project has demonstrated that bottom ash aggregate can be effectively substituted for a portion of the aggregates in a bituminous surface mixture. Based on observations and testing performed in this study, the following conclusions were drawn:

1. The Marshall Mix design results indicate that asphalt mixes containing bottom ash have higher optimum asphalt contents than standard asphalt mixes.
2. The optimum wet bottom ash replacement is 16 % for binder course and 25% for wearing course by weight of the mixture
3. Marshall Stability and flow values have been found to decrease as the percentage of Wet bottom ash is increased
4. Although the bottom ash increases the bitumen requirement in the mix, price per unit surface area decreases, as its low density of bottom ash asphalt mx. Therefore the bottom ash replacement is economically feasible
5. Production rate of bottom ash is at the satisfactory level for overlaying of nearly 180 km surface layer per day.

The properties of HMA containing bottom ash are dependent on ash content. As the ash content was increased, the optimum asphalt content, the air voids and the voids in mineral aggregate were also increased, while the mixture density and the stability of HMA mix were decreased. However, the mix is highly resistant to moisture induced damage (stripping) because of low water absorption rate of bottom ash particles.

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Actually, the addition of bottom ash required an increase in asphalt content which is not economically viable. Due to the porous nature of bottom ash particles, the absorption of asphalt binder is higher than conventional fine aggregate. Hence, from a purely economic standpoint, bottom ash may not be a cost effective choice. However, the bulk specific gravity of bottom ash blended mix is lesser than bulk specific gravity of conventional mix for both layers. This is due to the low density of bottom ash particles. As a result, although the bottom ash increased the binder requirement and cost per 1 Mt of the mix, the overlay area per unit weight is higher than the conventional mix. Therefore, a considerable savings can be seen.

It was found that, the wet bottom ash could be used as an alternative material for fine aggregate in flexible pavement construction. Asphalt mixes with bottom ash can be designed in the same way as with conventional aggregates. From the obtained results, the bottom ash replacement should not be more than 25% for wearing course and 16% for binder course due to the fact that high bottom ash content causes higher binder requirement and the low stability in the mixture.

Bottom ash containing mixes have relatively high air void contents. The high air voids are caused for the rough surface texture of bottom ash particles, which also produces a high angle of internal friction. Therefore, enhanced skid resistance can be accepted.

Finally, it was concluded that the properties of bottom ash collected from Norochcholai coal power plant can meet the specifications for conventional aggregates and can be successfully used in hot mix asphalt concrete in Sri Lanka while enhancing not only the mixture properties but also skid resistance and resistance to striping. In addition it provides economical savings to the highway agencies and environmental friendly cost effective solution for the waste problem of the power plant.

## 6.2 Further Studies

Initial evaluations were done on laboratory results. The field test for performance evaluation of asphalt pavement sections should be done on a regular basis between the control and bottom ash asphalt mixes.

Further research should be performed to study the differences in bottom ash properties obtained from different power plants and how these properties affect the performance of bottom ash asphalt mixes. In addition, the consistency of the bottom ash produced by a single plant should also be evaluated.

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