STABILIZATION OF FLY ASH FROM MEDICAL WASTE INCINERATION AS FILLER MATERIAL IN FLEXIBLE PAVEMENT

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Stabilization of Fly Ash from Medical Waste Incineration as Filler Material in Flexible Pavement

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DEDICATED

To

My Family

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ABSTRACT

Fly ash from medical waste incineration contains toxic heavy metals that act as groundwater contaminants due to their leaching characteristics when exposed to the environment. This problem becomes acute due to limited safe disposal options, and therefore it can become a severe environmental burden in Bangladesh. This study examines the effects of using fly ash from medical waste incineration (MWIFA) in the bituminous mixture as mineral filler as an alternative to conventional stone dust (SD) filler. Marshall samples were prepared with varying filler ratios of 0%, 2%, 4%, 6%, 8%, and 10% to determine optimum bitumen ratios and investigate engineering properties. MWIFA filler and SD filler were used in the hot bituminous mixes by adding varying percentages of bitumen from 4.0% to 6.0%. Several parameters such as Marshall stability, flow, unit weight, air voids (Va), voids filled with asphalt (VFA), and voids in the mineral aggregate (VMA) were determined for all mixes. The optimum bitumen ratios for each filler percentage are selected based on the respective results of these parameters. The optimum bitumen contents of all filler ratios were within 4.9 % to 6.5%, satisfying the standard range of Bangladesh Roads and Highway. All the parameter values for both fillers at respective optimum bitumen contents satisfy the Marshall method mix design criteria. The highest stability values for MWIFA and SD fillers are 25.80 kN and 27.82 kN, respectively, found at 10% filler. The lowest stability loss was found from the mixture prepared with 8% MWIFA filler among all the hot bituminous mixes, as determined by mechanical Marshall immersion tests. The optimum filler contents for MWIFA and SD fillers are found at 5.5% and 9% filler percentages, respectively. The bituminous mixes with 5.5% MWIFA as mineral filler would give better performance in wearing actions, whereas mixes with 9% SD filler will exhibit the same performance.

The leaching behaviour of the specified heavy metals (As, Pb, Cu, Cr, Ni, Cd, Hg and Zn) has been analyzed using the Toxicity Characteristics Leaching Procedure (TCLP) and found to be insignificant. The heavy metal concentrations obtained from the TCLP test results are far below the USEPA regulatory limits. The cumulative concentrations of heavy metals (Cd, Ni, Zn, Cu and Pb) were found far below the Dutch regulatory limit (U1) from NEN 7345 Dutch tank leaching tests. The recommended proportion of medical waste incineration fly ash can be 5.5% (by total aggregate weight) for producing Marshall samples of optimum quality. The test results show that fly ash from medical waste incineration can be used efficiently as a filler material in asphalt paving mix replacing conventional fillers, especially in areas where MWIFA is abundantly available and easily accessible. MWIFA can be considered an eco-friendly mineral filler replacement as it has proven to be successfully recycled in pavement construction.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectroscopy
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Content
ACV	Aggregate Crushing Value
AI	Asphalt Institute
AIV	Aggregate Impact Value
ASTM	American Society for Testing and Materials
BC	Bitumen Content
BS	British Standards
CA	Coarse Aggregate
DI	Deionized
DNCC	Dhaka North City Corporation
DSCC	Dhaka South City Corporation
EI	Elongation Index
FA	Fine Aggregate
FI	Flakiness Index
HCE	Healthcare Establishments
HLRW	High Level Radioactive Waste
HMA	Hot Mixed Asphalt
IWAG	International Ash Working Group
LAA	Los Angeles Abrasion
LDR	Land Disposal Restrictions
LGED	Local Government Engineering Department
MF	Mineral Filler
MOHFW	Ministry of Health and Family Welfare
MSW	Municipal Solid Waste
MWC	Municipal Waste Combustion
MWIFA	Medical Waste Incineration Fly Ash
NBS	National Bureau of Standards
NEN	Netherlands Standardization Institute

OBC	Optimum Bitumen Content
OCS	Oil Contaminated Soil
OFC	Optimum Filler Content
OPC	Ordinary Portland Cement
PAH	Poly Aromatic hydrocarbons
PFA	Pulverized Fly Ash
RHD	Roads and Highways Department
S/S	Stabilization and Solidification
SD	Stone Dust
SEM	Scanning Electron Microscopy
SPLP	Synthetic Precipitation Leaching Procedure
SSD	Saturated Surface Dry
TCLP	Toxicity Characteristic Leaching Procedure
TFV	Ten percent Fines Value
USEPA	United States Environmental Protection Agency
UTS	Universal Treatment Standard
VFA	Voids Filled with Asphalt
VMA	Voids in Mineral Aggregate
WHO	World Health Organization
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
ZHE	Zero-Headspace Extractor

Chapter 1

INTRODUCTION

1.1 Background

Medical waste is a source of pollution and contamination for both humans and the natural environment. Bangladesh, a developing country, is continually moving forward to keep its economic balance in line with its rapidly growing population. Hospitals, clinics, private individual practitioners, dental clinics, diagnostic centers, and pathology services are growing as healthcare providers to meet the demands. Annually 93,075 tons of medical waste is produced at an average rate of 0.8-1.67 kg/bed/day in Bangladesh (Syed et al. 2012; MOHFW 2011). The steps of medical waste management include segregation at source, autoclaving, chemical disinfection, shredding, recycling, deep burial, incineration, and disposal. Incineration of the medical waste and then dumping the incinerated ash into landfills is the most common practice adopted to dispose of medical waste (Azni et al. 2005).

According to Zhao et al. (2010), although the incineration process can reduce the volume of waste by 70%, there remains lots of residue in the form of a fly and bottom ashes. Ashes from medical waste incineration contain a high level of heavy metal. A study by Kimani (2007) concluded that fly ash and bottom ash produced from medical waste incineration are enriched with heavy metals such as As, Cd, Cr, Hg, Zn, Ba, Cu, Pb, Mn, Cr, Ni, and Sn. Exposure to these causes damage to human beings, especially to fetuses, infants, and young children, as they cause respiratory, skin, and lung irritation and eventually lead to systematic failure.

On the other hand, fly ash can spread out to a greater distance by wind. They cause damage to the environment and public health when they are exposed to the environment. The exposure pathways to the receptors may be the air, soil, surface water, and the entering food chain.

When the heavy metal present in the fly ash enters the food chain through the leaching process, it causes bioaccumulation in the food chain. Inappropriate disposal of incineration fly ash leads to contamination of water supplies or local sources used by nearby communities or wildlife if the hazardous leachate enters into an aquifer, surface water, or drinking water system. (Agamuthu and Chitra 2009).

In the past, fly ash was released directly into the atmosphere. Recent concerns about environmental pollution have led to banning its release into the atmosphere and have issued some mandatory techniques to capture it before release. The pretreatment of fly ash is enforced in many countries, especially in the United States, China, Malaysia, and India, considering the harmful effects of medical waste incineration fly ash (Kumar et al. 2016; Agamuthu and Chitra 2009; Tzanakos et al. 2014).

In Bangladesh, the health care authorities do not pay attention to the proper handling and disposal of medical waste. The one recognized organization working for medical waste management in Bangladesh is PRISM Bangladesh having their branches at Khulna, Jessore, and Chittagong. They have incinerators only in the Dhaka branch, and in the other places, the landfilling system is adopted (Zerin and Ahmed 2009). The PRISM authority does not treat the incinerated fly ash to reduce the toxicity before dumping it into the landfill. Thus, it creates a potential threat of entering heavy metals into the aquatic life and food chain.

The land is scarce in our country. Dumping waste into landfills demands large land requirements, difficult to manage for a populous country like Bangladesh. So, the shortage of landfill areas for dumping and the environmental degradation of fly ash is an impending threat in a densely populated country like Bangladesh. Therefore, the stabilization of fly ash reduces the requirement of land for the disposal of fly ash. Stabilization and solidification is a technology that is gaining prominence to treat waste.

Several studies have shown that the medical waste incineration fly ash can be successfully stabilized in the construction materials using cement, Ceramic tiles, and synthetic geotextile (Agamuthu and Chitra 2009; Kumar et al. 2016; Al-Multairi et al. 2004). Stabilization lessens the hazard potential of waste by converting the contaminants into less soluble, mobile, or toxic forms. Solidification refers to encapsulating the waste in the construction materials and does not involve the chemical reactions of the contaminants and solid additives.

Nowadays, the demand for paving infrastructure is rapidly increasing in terms of traffic load and durability. Fly ash has been extensively used in concrete construction. However, there are limited applications where fly ash has been used on asphalt pavements (Asi et al. 2005; Faheem and Bahia 2010). The use of fly ash in asphalt materials has potential as it improves performance and decreases costs and environmental impacts (Tapkin 2008).

The application of medical waste incineration fly ash in asphalt technology is yet to be explored. Furthermore, most researchers have only studied the influence of fly ash on asphalt paving mixes without investigating the long-term leaching performance during the service life of the mixtures. This study inspects the suitability of medical waste incineration fly ash as filler in asphalt pavement.

1.2 Statement of the Problem

There are practices to manage medical waste in Bangladesh, but no treatment is found for the fly ash generated from medical waste incineration. Proper treatment of this fly ash is compulsory, considering the toxicity level of fly ash. Sobolev et al. (2014) used fly ash into asphalt mixtures to improve the performance of the asphalt binders. Most of the conducted studies did not provide any protocol on incorporating fly ash in standard pavement material production (Sobolev et al. 2013). Those studies did not introduce the long-term leaching effect on asphalt -fly ash incorporated matrix. Leachate originating from fly ash or solidified fly ash matrix contains toxic metals. So, an appropriate leaching test is obligatory to predict the long-term leaching behaviour of solidified asphalt fly ash matrix (Binner et al. 1997). Two tests, such as a diffusion dutch tank leaching test with acidic extracts and a TCLP test, have been used in this study to assess toxicity under an acidic environment.

In this study, both the Marshall properties and leaching characteristics of the asphalt fly ash incorporated solidified matrix has been evaluated.

1.3 Objectives of the Research

The specific objectives of the study can be summarized as follows.

a) To stabilize the fly ash from medical waste incineration into asphalt paving mix by confining the fly ash in asphalt mix and convert it into a less harmful solidified matrix.
b) To examine the Marshall and leaching properties of asphalt paving mixes containing different proportions of medical waste incineration fly ash as filler.
c) To determine an optimum percentage of fly ash to be used in asphalt paving mix as a filler material to ensure desirable Marshall Properties.

1.4 Scope of the Study

The proposed research work would assess the suitability of fly ash-incorporated asphalt pavement as a road construction material in Bangladesh based on its engineering and leaching characteristics. This stabilization of medical waste incineration fly ash in asphalt pavement as the filler material will probably lead to an alternative yet sustainable and economical way of hazardous waste management.

1.5 The Research Program

The experimental study was performed in three stages: preparing filler specimens, characterizing the materials and assessing the suitability of fly ash from medical waste incineration as mineral filler in asphalt paving mixes.

In the first stage, the fly ash sample was collected from the medical waste treatment facility operated by the PRISM Bangladesh Foundation, which owned a landfill site at Matuail, Dhaka South City Corporation. Fly ash samples were dried in an oven for 24 hours to ensure precise quality during the experiment. Subsequently, they were cooled to room temperature. After cooling, the samples were passed through the series of BS standard test sieves (#4, #8, #16, #30, #50, #100, #200) using a mechanical sieve shaker. The portion of the sample passing through the #200 sieve (75 microns) was used as mineral filler in the hot asphalt mixtures.

In the second stage, the properties of materials, i.e., bitumen, filler, and aggregates, were determined.

In the third stage, the suitability of medical waste incineration fly ash was evaluated. The Marshall Stability test was carried out to determine the optimum bitumen ratios from samples prepared with 0% (control), 2%, 4%, 6%, 8%, and 10% fly ash filler ratios. For each fly ash filler ration, multiple test specimens were prepared by adding varying bitumen percentages from 4.0% by weight of aggregates to 6.0% with an increment of 0.5%. The preparation, compaction, and testing of all specimens were conducted according to ASTM D1559 (Marshall Mix Design Method). The Marshall stability and flow tests were performed on each specimen, and their corresponding maximum load resistance and flow values were recorded. The bulk specific gravity and density (ASTM D2726), theoretical maximum specific gravity (ASTM D2041), and percent air voids (ASTM D3203) were determined for each specimen. The Marshall immersion test was performed to determine the optimum filler percentage. Two leaching extraction tests were performed on the Marshall specimens containing 0%, 2%, 4%, 6%, 8%, and 10% fly ash with respective optimum bitumen contents. The toxicity characteristic leaching procedure (TCLP) was conducted according to USEPA 1311 method. The Netherlands tank leaching test was performed following NEN 7345 guidelines, and the extracts were analyzed for heavy metals using AAS (Shimadzu AA-7000).

1.6 Thesis Organization

The thesis is divided into five distinct segments covering the following topics:

Chapter -1 gives a discussion on the background and statement of the problem and objectives of this study.

Chapter -2 covers the literature review related to the topics that include discussion on medical waste incineration fly ash, solidification or stabilization technologies available, stabilization techniques of fly ash in asphalt pavement, and the difference between our method and the method followed in the previous studies. Appropriate leaching procedure of asphalt fly ash solidified matrix mixture is also emphasized in this chapter. Finally, a summary of the complete literature review is provided at the end of the chapter.

Chapter 3 describes the experimental program and techniques employed in this research and also describes the short description of the tests and the properties of raw materials to perform those tests in the study.

Chapter 4 enumerates the analysis of test results on asphalt mixes. It also includes the finding on the evaluation of medical waste incineration fly ash as compared to that of traditional filler and mixes regarding Marshall properties as well as leaching performance,

The conclusions of the complete study and some recommendations for future research are presented in Chapter 5. All raw data used in this research are attached to this report in an appendix section.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses medical waste incinerated fly ash, stabilization techniques of fly ash in asphalt pavement. Leaching test procedures of asphalt fly ash solidified matrix mixture is also discussed in this chapter.

Fly ash has been recycled as an engineering material for many years because of its pozzolanic characteristics (Ghosh and Subbarao 1998). The increased cost and potential environmental impacts of landfilling have caused regulatory agencies to encourage the more beneficial use of fly ash (Ghodrati et al. 1995). However, few researchers tried to study the possibility of medical waste incineration fly ash as a replacement of mineral filler for pavement material, especially in Bangladesh. This study is designed to assess the possibility of using medical waste incineration fly ash as mineral filler in asphalt mixtures by studying the performances and leaching parameters of mixes.

2.2 Medical Waste Incineration Fly Ash

Medical waste incineration fly ash is a kind of incineration residue of hazardous medical waste, and it contains toxic metals and organic pollutants (Liu et al. 2018). Medical waste is produced from healthcare and indicated as infectious waste (Klangsin and Harding 1998; Levendis et al. 2001; Lee et al. 2002a). Among various methods, disposal of the residue ash into a landfill after incineration is the most popular method used widely to manage medical wastes (Xie et al. 2009). Hong et al. (2000) showed that solid waste incineration causes 90% volume and 75% weight reduction of total waste. The residue ashes produced from incineration contain various toxic chemicals, such as heavy metals (Jung et al. 2004). Eighmy et al. (1995) showed that fly ash is more hazardous than bottom ash since it quickly becomes airborne and contains a high concentration of volatile elements, including precarious heavy metals (e.g., Zn, Cu, Pb, Mn, and Fe). The dumping of such fly ash into landfills may pose severe environmental degradation and health deterioration of the leading species of earth. That is why the MWIFA must be treated appropriately to avoid secondary pollution.

2.3 Management of Medical Waste Incineration Fly Ash in Bangladesh

Medical waste generation has increased significantly worldwide in the last few decades (Rajor et al. 2012). Annually 93,075 tons of medical waste is produced at an average rate of 0.8-1.67 kg/bed/day in Bangladesh (Syed et al. 2012; MOHFW, 2011). There were no authorized medical waste treatment plants or dumping facilities in Bangladesh until 2004. In all health care facilities, the disposal of pharmaceutical wastes and pressurized containers (e.g., inhalers, spray cans, etc.) existed along with the general waste. Prism Bangladesh is a non-profit voluntary development organization established in 1989. It has been working to collect, manage, and treat medical and clinical waste from 484 HCEs in DSCC and DNCC areas since 2005. The collected medical waste goes through segregation before incineration. Bottom ash (BA) and fly ash (FA) are two residuals of the incineration process (Akyildiz et al. 2017). The organization authority dumps the residual ashes into a nearby landfill for final disposal. The heavy metals in the fly ash enter the food chain through the leaching process and cause bioaccumulation in the food chain (Kimani 2017). Disposal of this fly ash in the landfill area needs careful attention to prevent these heavy metals from re-entering into the environment (Agamuthu and Chitra 2009).

2.4 Treatment of Medical Waste Incineration Fly ash

The most traditional practice for reducing the contamination effects of fly ash is to dispose of the ashes into controlled landfills. Recently, the absence of ample disposal spaces, high cost, strict guidelines, and frequent public opposition to the sifting of new landfills are creating difficulties day by day, especially in densely populated cities (Cangialosi et al. 2006; Anamul et al. 2012).

Thus, it becomes essential to treat the toxic incinerated fly ash before disposal (Akter 2000; Dermatas 2001). Now, several conventional methods are used to treat fly ash. These methods are classified into three categories, such as (1) separation, (2) solidification/stabilization (S/S), and (3) thermal (melting, roasting, sintering, and low-temperature treatment (Quina et al. 2008; Zhou et al. 2017). These methods either remove heavy metals from fly ash or stabilize heavy metals in an insoluble form.

Among various technologies available to increase the retention capacity of fly ash, the solidification and stabilization (S/S) technique have been gaining prominence in recent times because of its dual advantage. "Stabilization" of toxic waste includes mixing the waste with a binding material and reducing its toxicity characteristics and mobility of the heavy metals from waste before disposal. It converts hazardous waste into an environmentally acceptable waste form for land disposal or construction use (Dermatas 2001). Stabilization/solidification, a pre-landfill waste treatment method, is specifically appropriate for wastes containing heavy metals (Malviya and Chaudhary 2006). Agamuthu and Chitra (2009) refer to stabilizing fly ash in construction materials for secure and effective disposal.

2.4.1 Stabilization and Solidification

The stabilization/Solidification (S/S) process has significantly developed environmental technology. S/S has been widely used to dispose of low-level radioactive, hazardous, and mixed wastes, as well as remediation of contaminated sites. According to the US Environment Protection Agency (USEPA), S/S is the best demonstrated available technology (BDAT) for 57 hazardous wastes. As a result, many S/S methods are being promoted and offered to treat hazardous and other waste types from industry, municipalities, and government sources.

Solidification denotes a technique that condenses the waste in a monolithic solid of high structural integrity without excessive chemical collaboration between the waste and the used reagents. Pollutant movement will be controlled by enormously reducing the surface area exposed to leaching or detaching the waste within an impermeable shell.

Stabilization is the other constituent of S/S to transform the contaminants to less mobile and less toxic forms to generate a chemically stable state (Means 1995). The toxins in the waste remain in the solidified matrix even though the matrix itself might deteriorate with time.

Conner (1990) described that solidification/stabilization (S/S) is an economical process for disposing of many hazardous waste types. The method involves mixing liquid or semi-solid wastes with binders to produce a solid, structurally sound, and impermeable solid.

2.4.2 Previous Studies on Solidification or Stabilization Techniques

S/S technology was initially established to treat nuclear waste in the 1950s and was later used on different kinds of hazardous wastes. From around the 1980s, the technology was also practiced to treat toxic residues (Laugesen 2007). The heavy metals in many industrial solid by-products, ashes, sludge, etc., can be stabilized into the glass and ceramic matrices, cement matrices, bricks, and mortars, protecting human and environmental health.

Donald et al. (1997) stabilized high-level radioactive waste (HLRW) and surplus materials from various commercial sources in glass and ceramic hosts.

Mahzuz et al. (2009) assessed and examined arsenic-contaminated sludge stabilized in the ornamental brick. It showed that the compressive strength decreased with an increase of sludge proportion up to 4 %.

Li et al. (2001) stabilized factory sludge with different portions of ordinary portland cement (OPC) and pulverized fly ash (PFA). The author examined the chemical speciation and the leaching behaviour of heavy metals in these cement-based waste materials by different sequential extraction procedures and regular TCLP tests.

2.4.3 Previous Studies on Solidification or Stabilization Techniques on Fly Ash from Medical Waste Incineration

The studies of the stabilization/solidification of medical waste incineration ash are limited. Some studies have been mentioned below.

Singh et al. (2016) investigated through experiments to determine the effect of partial replacement of cement with biomedical waste ash. Results showed that workability decreased with an increase in replacement level at a constant dose (0.6%) of superplasticizer. It also showed that the density of fresh concrete decreased marginally with the increase in replacement level. Moreover, the compressive strength of concrete made using biomedical waste ash is more than that up to 7.5% replacement level, and up to 10% replacement level is comparable to the conventional concrete.

Tzanakos et al. (2014) used bottom and fly ash generated from incinerated medical waste as a raw material for the production of geopolymers. The stabilization (S/S) results showed that hospital waste ash could be utilized as source material for the production of geopolymers. The adding fly ash and calcium compound considerably improve the strength from 2 MPa to 8 MPa of geopolymer specimens. Finally, the solidified matrices indicated that the geo polymerization process could decrease the amount of heavy metals found from the hospital waste ash leaching.

Anastasiadou et al. (2012) presented that the TCLP leachates of the untreated medical waste ash contained high concentrations of Zn and Pb and lesser amounts of Cr, Fe, Ni, Cu, Cd and Ba and evaluated the mechanical properties of the medical waste incineration ash using different amounts of ordinary Portland cement (OPC) as a binder. The results showed that strength decreased as the percentage of fly ash increased. The exhibited compressive strength values after 28 days were 12.7 MPa for 60% cement mixed with 40% fly ash and 16.12 MPa for the mixture of 60% cement and 40% bottom ash. The compressive strength was reduced to 1.30 MPa when 30% cement was mixed with 70% fly ash and 7.95 MPa when 30% cement was mixed with 70% bottom ash.

Al-Rawas et al. (2005) studied the possible use of incinerator ash as a replacement for sand and cement in cement mortars by preparing two sets of mixes. Two sets of specimens were prepared. Cement and water quantities were kept constant, and incinerator ash was replaced at 0%, 10%, 20%, 30% and 40% by weight percentages for sand in the first set. In the second set, incinerator ash was replaced at ratios of 0%, 10%, 20% and 30% by weight for cement and sand and water quantities were fixed. The cement, sand and water mixing proportion used in the study was 1:3:0.7, respectively. The results denoted that incinerator ash used as a replacement for sand reduced the slump values but increased the slump values used to replace cement. The mix prepared with 40% incinerator ash by replacing sand showed a higher compressive strength value than the mix without incinerator ash for most curing periods. The maximum compressive strength of the sample with 20% incinerator ash was 36.4 MPa after 28 days of curing. Specimens set using 20% incinerator ash replacement for cement produced a higher compressive strength (27.4 MPa) than the control mix at 28 days curing period.

Reijnders et al. (2005) investigated that 50 % of the ash produced from incinerated waste in manufacturing sound insulation walls at National roads in Germany. Around 60% of the bottom ash was used to construct asphalt and a sub-layer of roads in the Netherlands. Above 72% of ash is reused to manufacture parking spaces, cycling tracks and other roads in Denmark.

Aubert et al. (2004) assessed the use of biomedical waste ash on the compressive strength and the durability of hardened concrete and suggested optimum percentage value of fly ash using in concrete, and gave the confirmation to utilize the material with ensuring environmental safety from the leaching tests carried out on the concrete.

Al-Mutairi et al. (2004) evaluated the effectiveness of reusing hospital incinerator ash by comparing the compressive strengths of mixtures made with bottom and fly hospital ash with micro silica and conventional concretes. The effect of various percentages of micro silica, fly ash, and bottom ash on the compressive strength was also evaluated at 25°C, 150°C, 250°C, 500°C, 600°C, and 800°C. It was shown that for the 5% micro silica and fly ash incorporation, the compressive strength of the cubes was significantly increased, but for the replacement of cement by 15%, 20%, and 25% fly ash, bottom ash, and micro-silica gave lower compressive strength and reduced the workability. It could be noticed that the optimal for silica and fly ash replacement is 5%. At 25% cement replacement above 250°C, the compressive strength of bottom ash and micro silica was almost equal.

Filipponi et al. (2003) studied the different mixes prepared by blending bottom ash from hospital waste incineration with ordinary portland cement in different proportions and different water dosages. Bottom ash exhibited weak pozzolanic property at curing times more than 28 days and waste dosages higher than 50%.

2.5 Stabilization in Asphalt Concrete

Recent research focuses on using waste materials in highway constructions and road layers from the top layer to subgrade. Advanced performance and environmentally friendly road pavements can be erected by using by-products instead of traditional materials. This practice engages the road construction industry on track towards sustainable construction practices (Huang et al. 2007; Saltan et al. 2015). Hence, several researchers have tried to study the possibility of using waste material in pavement construction. Kandhal (1993) suggests the recycling of waste materials in highway construction.

Modarres and Rahmanzadeh (2014) used coal waste powder as filler in hot mix asphalt (HMA). They found better results of the indirect tensile strength, Marshall Stability, and resilient modulus tests of hot mix asphalt (HMA) mixes than limestone powder.

Sutradhar et al. (2015) found the effective use of waste concrete dust and brick dust as fillers instead of generally used fillers such as fine sand and stone dust in asphalt concrete without compromising Marshall design criteria.

Saltan et al. (2015) studied the potential use of cullet glass and domestic waste glass dust as mineral fillers in the asphalt concrete mix and compared it with limestone filler mixtures. The Marshall stability and flow values for all types of filling (limestone, cullet glass, and glass waste for domestic use) met the specification limits of the Turkish general direction for motorways.

Bhageerathy et al. (2014) investigated the performance of bituminous mixes modified with bio-medical plastic waste and compared it with the usual mix. The Authors determined the mixture properties by conducting Creep tests and indirect tensile stiffness modulus tests and found better properties for Plastic Coated aggregates than normal aggregates.

Raji et al. (2009) stated that mixes prepared with biomedical syringe and glucose plastic waste had better Marshall stability than the conventional bituminous mixes.

2.6 Asphalt Concrete Pavement

Roads consist of sub-grade, substructural, and surface layers formed in many layers; these layers together are the pavement. Because asphalt concrete is much more resilient than Portland concrete, asphalt concrete flooring is often referred to as flexible flooring. Asphalt concrete consists mostly of an asphalt binding aggregate. Usually, aggregates constitute about 95% weight of an asphalt mixture than the asphalt binder (the remainder 5%). The traditional asphalt mixture consists of 85% aggregates, 10% asphalt and 5% air vacuum by volume. The asphalt binder sticks the aggregate together, meaning that the stone or gravel is crushed without the asphalt binder. Many HMA mixtures are supplemented with small additives and admixtures to increase their efficiency or working ability.

2.6.1 Flexible Pavement Layers

Asphalt concrete pavements are not a thin covering of asphalt concrete over the soil; they are engineered structures composed of several layers. Figure 2.1 illustrates a vertical section of the flexible pavement structure.

2.6.1.1 Subgrade

The border between the base soil and the upper pavement layers is the regular soil floor, called the foundation. The soils in the area, recognized as the subgrade, are the base supporting the road. The subgrade is the bottommost layer that receives loads from the top layers. So, the stresses coming from top layers should be within the limit of sub-grade capacity. Only compacted or combined with the asphalt emulsion, the foamed asphalt, portland cement, lime, or other patented stabilizing materials can stabilize the subgrade, following the elimination of topsoil and other organic materials. Moreover, thick layers of base course, sub-base course and surface course are provided to lessen the stress on sub-grade soil.

Figure 2.1 Flexible Pavement Layers (Mehari 2007)

2.6.1.2 Sub-base layer

The material layer between the subgrade and the base course is the sub-base course. It provides structural protection, increases ventilation, and decreases infiltration of subgrade fines into the pavement construction. In comparison, the sub-base course with more fines will act as a filler between subgrade and base course if the base course is free graded. The sub-base course is often omitted from the pavement, and the subgrade soil is directly put on a comparatively dense base course.

2.6.1.3 Base Course Layer

The base course is the layer of a defined engineered thickness material positioned directly underneath the (wearing) or binder course of the pavements. It offers additional delivery of loads and contributes to drainage. It can consist of crushed stone, crushed slag, and other untreated or stabilized materials.

2.6.1.4 Asphalt Binder Course

The binding course is a hot mixed asphalt (HMA) course between the wearing path and either a granular base course or the stabilized baseline. Existing pavement or other HMA binder path helps dispense loads of road traffic so that the transferred stresses do not permanently warp the paving foundation.

2.6.1.5 Asphalt Wearing Course

It is the top layer of the floor, directly subjected to traffic and environmental powers (Commission of the Transport Study Council, 2011). The wearing course has features including inertia, smoothness, noise suppression, resistance to rutting and shoving and drainage. It also avoids surface water intrusion into the HMA layers, bases, and subgrades of the underlying layers.

2.6.2 Mineral Filler

Filler is one of the most significant components of the asphalt paving mix that affects the asphalt concrete mixtures (Anderson et al. 1992). Zulkati et al. (2012) found that well-packed aggregates (coarse aggregates and fine aggregates) combined with filler acts as the backbone of the asphalt mixture. High filler percentage enhances better cohesive and internal stability to the pavement, but excess filler may weaken the mixture by increasing the asphalt amount needed for coating the aggregates (Kandhal et al. 1998). The maximum usage of flexible pavement in road construction is due to its superior service performance to drive comfort, stability, durability, and water resistance. The mixture of asphalt binder and mineral filler controls the overall performance of asphalt pavement mixtures (Anderson et al. 2001). Filler controls the mechanical properties of asphalt mixtures by providing additional contact points between larger aggregates and increasing the viscosity of asphalt binders (Wang et al. 2011; Diab and Enieb 2018). The Asphalt Institute recommends 4 % to 8% usage of filler in asphalt concrete (Rajitha and Koramutla 2019). The nature of filler affects the performance of the asphalt mixture. Sobolev et al. (2014) studied the viability of fillers, i.e., fly ash, lime, and cement in asphalt concrete using two different binders. The result demonstrated that the addition of these fillers significantly improved the rheological properties of the asphalt. The materials used as common filler materials like cement, limestone, granite powder etc., are not easily and economically available in Bangladesh (Sutradhar et al. 2015).

2.6.2.1 Previous Studies on Mineral Filler in Asphalt Mixture

Al-Qaisi (1981) examined the effect of filler to asphalt ratios on filler properties- mastic and asphalt paving mixture using five types of filler (Portland cement, lime dust stone, hydrated lime, powder of crushed gravel and Sulphur). He found that the filler type influenced the filler-asphalt ratio range at which the paving mixes would exhibit the desired properties.

Aschuri and Woodside (2007) studied the behaviour of asphalt concrete mixes with fly ash additive and found that the bitumen mixes containing fly ash additive with hydrated lime modifier were better than origin bitumen mixes.

2.7 Previous Studies Related to Solidification/Stabilization of Fly Ash as mineral filler in Asphalt concrete

According to Tapkin (2008), the stabilization of fly ash in asphalt pavement increases the mixture performance, reduces costs and adverse environmental impacts. Fly ash seals the voids and provides contact points between larger aggregate particles in asphalt concrete mixes. Thus, it acts as an appropriate filler material (Warden et al. 1952). Fly ash provides higher stability in asphalt mixtures (Sankaran 1973; Henning 1974; Tapkin 2008). The fly ash used in asphalt pavement must meet mineral filler provisions outlined in ASTM D242. There are limited studies of using fly ash in asphalt pavements (Faheem and Bahia 2010). Mistry and Roy (2016) investigated the suitability of fly ash as filler instead of hydrated lime in the hot asphalt mix. The results revealed that fly ash in hot mix asphalt (HMA) provides lesser deformation with well enough strength.

Al-Hdabi (2016) examined the properties of asphalt concrete mixture with rice husk ash as filler by performing Indirect Tensile Strength, Index of Retained Strength, and Marshall Stability tests. From the test results, rice husk ash as mineral fillers improved the Marshall stability value of hot asphalt mixtures than conventional mineral fillers.

Bi and Jakarni (2019) studied the prospective use of wood ash as a filler substitute in the asphalt mixture. The author conducted the Marshall Flow and stability tests, the asphalt permanent deformation tests, the indirect tensile fatigue tests, and the strength modulus tests using 25%, 50%, 75%, and 100% of wood ash filler instead of conventional fillers in the test samples. The results showed that the presence of wood ash in the asphalt mixture could improve fatigue performance, reduce permanent deformation, and increase the elastic modulus of the asphalt mixture.

Ramme et al. (2006) used Type C fly ash in asphalt mixtures and found fly ash could be an economical alternative to recycle flexible pavements for road reconstruction.

Naik et al. (1995) studied fly ash concrete mixture proportions for highway paving work, and results showed that these mixes would give an excellent alternative to conventional paving material.

From the previous literature results, it can be concluded that fly ash contributes to improving the properties and performance of the asphalt mixtures. However, the findings of the previous studies are often contradictory, and the validity of some of the presented results may be confined to specific fly ashes used in these studies. A limited study has been conducted on dense grade mixes with the use of MWIFA as filler. MWIFA is abundantly available, and thus its disposal becomes a burden for Bangladesh. Hence, an effort has been conducted to determine the suitability of MWIFA, which passes through a 0.075 mm BS sieve as a filler in bituminous concrete mixes by studying the fundamental engineering properties.

2.8 Leaching Test

Leaching tests are essential for the environmental assessment of solidified and stabilized contaminated waste (S/S) remediation methods. According to Barth and Wiles (1989), the main objective of the S/S process is to contain waste contaminants and prevent or minimize the release of the contaminant into the environment. According to Agamuthu and Chitra (2009), the leaching test is widely used in evaluating the retention capacity of S/S waste mass.

If water interacts or passes through a porous media, each constituent present in the solidified matrix would dissolve into pore water at some fixed rate. According to Conner (1990), there is no such thing as an absolute insoluble material.

Leaching is a process by which a component of waste is detached mechanically or chemically from the solidified matrix into solution by the passage of solvent, such as water (Richardson et al. 2002). The generated contaminated water that passes through the porous matrix is called leachate. Leachability is the capacity of the waste material to leach.

The release of contaminants from fly ash influences the groundwater quality controlled by several factors such as water source, pH, time, temperature, etc. The leachate characteristics vary over time and space and even within a given landfill site. (Sobolev et al. 2013)

2.8.1 Liquid to Solid ratio

The liquid to solid (L/S) ratio in a leaching test affects the amounts of soluble pollutants perceived and represents the actual in-situ leaching characteristics. This ratio selection depends on practical considerations rather than on the actual evaluated situation. A High L/S ratio provides a sufficient amount of liquid for analysis, and liquid gets separated easily from the solid. However, if the intention is to simulate the systems at higher concentrations (such as pore water), the L/S ratio should be as low as possible.
However, it is necessary to consider how the L/S used to represent the in-situ condition in the leaching tests and how the differences in the L/S ratio may affect the results and prediction of long-term performance.

2.8.2 Laboratory Leaching Tests

Leaching tests should mimic the field conditions as close as possible. Further, they should be easy to control and model. It is essential to mention that many factors influence the leaching behaviour of materials under natural conditions. For electing the most appropriate leaching method according to conditions, one must mainly consider the chemical and physical properties of wastes, the formation of source, period of waste disposal, and climatic circumstances of the disposal area. Many researchers have recommended various leaching methods justifying the challenges.

According to Kosson et al. (2002), the scheming tests that simulate release under exact environmental setups are inadequate because of the lacking information on release environmental scenarios. They recommended an approach to assess the leaching potential of wastes over various standards for parameters having a remarkable impact on constituent leaching (e.g., pH, LS, and waste form) and considering the management scenario.

Typically, leaching tests can be categorized into the following classifications according to Environment Canada (1990): (a) tests under a specific environmental condition to simulate contaminant release, (b) successive chemical extraction tests, or (c) fundamental leaching parameters assessment tests.

Laboratory tests fall into two general categories: (1) single extraction/batch tests (sometimes referred to as "static" extraction tests); and (2) multiple extraction/flow-around and flow-through leaching tests (sometimes referred to as "dynamic" tests).

2.8.2.1 Toxicity Characteristics Leaching Procedure

According to Tsiridis et al. (2006), Toxicity Characteristic Leaching Procedure (TCLP Method 1311) is generally used to determine the leaching characteristics of fly ash established by the US Environmental Protection Agency (USEPA, 1992). This procedure offers a uniform method to compare the tendency of inorganic elements to leach out from fly ash samples into moderate-to-highly acidic aqueous environments. The heavy metal content concentration in fly ash can be compared with different legislation to utilize fly ash. TCLP has been considered a regulatory tool to identify hazardous wastes.

Xue et al. (2009) performed TCLP tests to determine the environmental impacts of utilizing municipal solid incineration ash in a stone mastic asphalt mixture. The test results showed that the cumulative metal leaching capacity increased with leaching times and lower pH of leachate. Furthermore, the heavy metals excluding Ni found in TCLP tests such as Cu, Cd, Pb, Zn, Cr can be stabilized effectively in asphalt mixture.

2.8.2.2 Leaching of Monolithic Fly Ash

Leachate originating from fly ash or solidified fly ash matrix may contain toxic metals that pollute groundwater (Binner et al. 1997). The International Ash Working Group (IAWG), based in Europe, has done extensive work on incorporating a variety of tests into a comprehensive leaching system (Eighmy and van der Sloot 1994; van der Sloot 1998). A range of tests may be mandatory to forecast the leaching behaviour of the waste form in the environment of deposition (Bone et al. 2004; Schuwirth and Hofmann 2006).

Several leaching tests (single batch extraction tests, column tests, monolith tank tests, lysimeter tests) have been used to test raw MWC (Municipal Waste Combustion) ash, stabilized MWC ash, and MWC ash-amended asphalt and cement products.

Baur et al. (2001) inspected the factors governing the leachate configuration of cement stabilized air contamination control residues from municipal solid waste (MSW) incineration ash using laboratory tests and a pilot landfill. They compared the results from batch leaching tests and dynamic tank leaching tests with field lysimeter data.

2.8.2.3 Dutch Tank Leaching Test

Kosson et al. (2002) recommended methods similar to NEN 7345, the Dutch Tank Leach Test. This approach offered the potential to estimate leaching much more accurately (than many currently used leach tests relative to field leaching.

The Dutch Tank Leach Test (NEN 7345) is an immersion test used to control the leachability of the inorganic elements from building materials, monolithic waste, and stabilized waste materials.

Samples (minimum size = 40 mm) are suspended in a tank to consent to contact with de-mineralized water leaching fluid along all sides. The tank is full of liquid up to a designed L/S ratio for tests. The liquid is changed and analyzed at pre-set intervals (8 hours and 1, 2, 4, 9, 16, 36, 64 days). The test results allow the user to identify the controlling mechanism of leaching: dissolution, erosion, or diffusion. The obtained test results are in mg/m^2 (cumulative) against time

Limitation of the test

a) The test is only appropriate under aerobic conditions.

b) The test is valid for inorganic constituents.

c) The leaching fluid is pH-adjusted reagent water, which does not include the ionic strength of saltwater found in marine and estuarine environments.

d) This short-term test may not simulate long-term leaching.

2.9 Previous Studies Related to Leaching Characteristics in Asphalt concrete

Studies have assembled information about leaching tests to evaluate the use of solid wastes in highway construction (Bauw et al. 1991; Fallman and Hartlen 1994; Mulder 1991). However, few studies deal with the leaching test of asphalt pavement material incorporated with fly ash.

Kim et al. (2016) discussed the leaching behaviour of municipal solid waste incineration Bottom Ash used in hot mix asphalt by Synthetic Precipitation Leaching Procedure

(SPLP) batch testing. The release elements met the criteria of the US Secondary Drinking Water Standard (except Al).

Shedivy et al. (2012) investigated the leaching characteristics of poly-aromatic hydrocarbons and heavy metals from five different sources of recycled asphalt pavement through batch leaching experiments with TCLP fluid and DI water as a leaching solution. This study shows that pollutant leaching concentrations were low for many heavy metals and PAHs studied.

Hassan et al. (2008) presented the results of investigating the permeability and leaching of asphalt concrete mixes containing oil-contaminated soil. The results showed a significant decrease in permeability with the addition of OCS up to 30%. From the leaching test results, concentrations of the heavy metals were well below the TCLP regulatory limits for all OCS mixes.

Several projects have focused on accelerated leaching tests to predict long-term leaching behaviour (Caldwell et al. 1994; Meij and Schaftnaar 1994; Eighmy et al. 1997).

Červinková et al. (2007) tested the long-term impact of stabilized/solidified hazardous waste in asphalt emulsion on the environment by modified dutch tank leaching tests using acidic extract solutions and mathematical modelling. Based on the experimental and modelling data, the stabilized waste does not affect the environment in an alkaline pH condition. Many researchers recommend tank leaching tests to estimate the rate of metal leaching from ash-amended pavement pieces. (Hudales 1994; Kosson et al. 1996; Eighmy et al. 1995)

Kosson et al. (1996) tested ash-amended asphalt pieces with the Dutch method or a modification thereof. This practice provides a uniform method to compare the leaching tendency of inorganic elements from fly ash samples into moderate-to-highly acidic aqueous environments. It aids in relating the heavy metal content concentration in fly ash with different legislation to utilize fly ash.

2.10 Summary

This research has demonstrated the technical possibility of confining the medical waste incineration fly ash in the construction materials. The literature review also revealed that nowadays, many countries are exploiting the potential of fly ash as mineral filler, mainly to improve stability, durability, and elasticity of asphalt mix and in some counties to reduce their waste disposal problems. However, few study documents emphasized the leaching potential of heavy metals from solidified asphalt fly ash matrix. Stabilization of medical waste incineration fly ash is necessary for Bangladesh, mostly in built-up areas owing to the scarcity of landfill areas and environmental concerns. There is a strong need to study the performance and leachability of medical waste incineration fly ash in asphalt mixes.

Chapter 3

METHODOLOGY

3.1 Introduction

This chapter narrates the experimental design of stabilizing the medical waste incineration fly ash in asphalt concrete. Marshall Mix Design method is considered ascertaining the optimum bitumen percentage and subsequent optimum fly ash filler percentage. The chapter describes raw materials used in mix design, collection, and processing of the medical waste incineration fly ash, tests on aggregates, bitumen, fly ash, and mixes. Moreover, leaching tests for the toxic solidified asphalt fly ash matrix are illustrated in this chapter. A schematic diagram of the experimental program performed in this study is illustrated in Figure 3.1.

3.2 Materials

3.2.1 General

Hot mix asphalt concrete components include aggregate, asphalt binder, and mineral filler. Mineral filler affects the performance of the pavement. Bitumen acts as a binder in pavement production. The research work would require bitumen, aggregate, and medical waste incineration fly ash as raw materials. Other constituents excluding mineral fillers are kept the same throughout the entire experiment process to study the effect of fly ash as mineral fillers in mixes. A brief description of these ingredients and their characteristics is conferred below**.**

3.2.2 Bitumen

The asphalt binder constituent of a flexible pavement encloses the aggregate particles together. Mostly, up to 4 to 6 percent of asphalt bitumen used asphalt mixture. The physical characteristics of bituminous material, whether natural or manufactured, can differ markedly from another. The variety of bitumen gives it comprehensive utility in the building and construction industry. The quality of bitumen depends on its crude source, refining process, and chemical composition. The properties of binders are often enhanced using additives or modifiers to amend stripping resistance, flow, oxidation characteristics, and elasticity. Modifiers include oil, filler, powders, fibres, wax, solvents, emulsifiers, wetting agents, and other proprietary additives. Properties of Bitumen and their testing specification are given in Table 3.1.

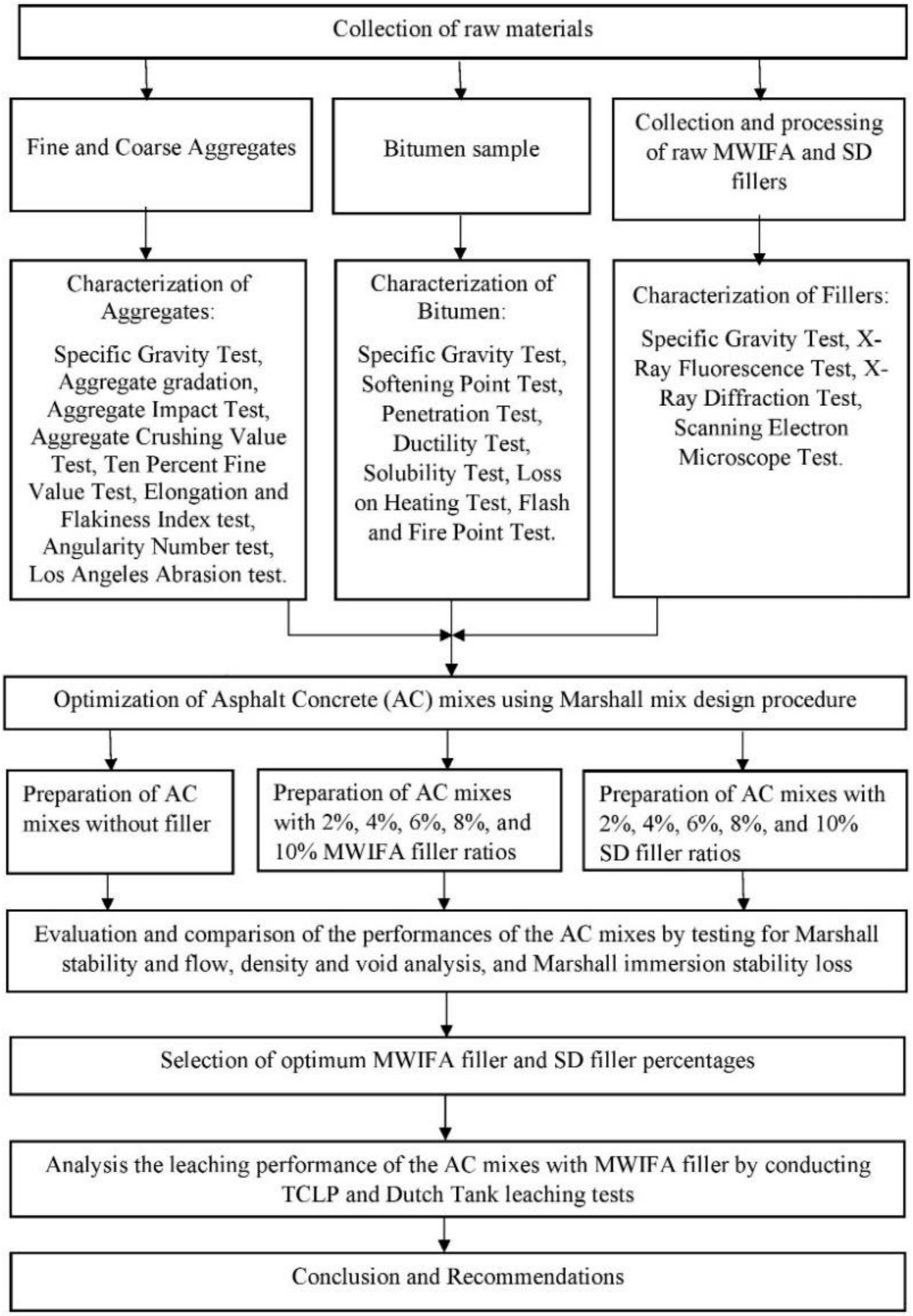


Figure 3.1 Flow diagram of the Experimental program

Table 3.1 Properties and test methods for Bitumen

Properties	Test Method	
	AASHTO Designation	ASTM Designation
Penetration at 25˚C (0.1mm)	T 49	D5
Flash Point (˚C)	T 48	D92
Fire Point (˚C)	T 48	D92
Ductility at 25 ˚C (cm)	T 51	D113
Solubility in Trichloroethylene (%)	T 44	D2042
Loss on Heating (%)	T 179	D6
Softening Point (˚C)	T 53	D36
Specific Gravity at 25˚C	T 43	D70

3.2.3 Aggregates

Aggregate is used in bituminous concrete, as granular base course, sub-base course, and pavement construction course. The physical properties and mechanical properties of aggregate significantly affect the mix properties. Binder content and processing of mix depend on aggregate gradation to some extent in the mix design. In this research, aggregate gradation will be modified with the varying percentages of mineral fillers. The properties of coarse aggregate, fine aggregate, and mineral filler are bestowed in the following subsections.

3.2.3.1 Coarse Aggregate

Aggregate passing 25mm and retained #8 sieve is termed as coarse aggregate. Generally, crushed stone, crushed gravel, or crushed boulder are used as coarse aggregate. It conquers the central part of the total volume of the mix. The behaviour of bituminous mixes is hugely affected by the gradation and quality of coarse aggregate. The value of the Marshall Stability of the mix depends on the characteristics of the coarse aggregate used. Hence, the selection of the proper coarse aggregate of the desired gradation is essential. Besides, it should be a clean, tight, durable material free from vegetable matter, soft particles, and other objectionable matter. Stone chips would be used as coarse aggregate in the mix available in Sylhet. The maximum size of the coarse aggregate that would be used in the mix is ¾ inch (19 mm).

3.2.3.2 Fine Aggregate

Fine aggregate (Passing #8 and retained #200) occupies the inter-spaces of coarse aggregate. It comprises natural sand, stone screenings, or a combination of both. It should also be composed of clean, hard, durable particles, rough-surfaced and angular, free from any objectionable matter. Stone screenings would be used as a fine aggregate. The screening is produced when stones are crushed with mechanical crushers.

3.2.3.3 Mineral Filler

Properties of bituminous materials depend not only upon the quality of binder and aggregates but also upon filler properties. Such factors influence bituminous materials as the amount and mineral composition, the grading and shape of the grains, micro-coarseness, and the specific activity of filler. Mineral Filler (MF) fills the voids in the aggregate and increases the density of the compacted mixes. The fraction of aggregate passing #200 sieves is Mineral Filler. Limestone dust or similar rock dust, portland cement, hydrated lime, silica cement, and other mineral matter are used as mineral filler. Our experimental samples are prepared using medical waste incineration fly ash as filler. We used stone abrasion dust as a conventional filler in our control samples to compare the results.

3.2.3.4 Gradation of Aggregate

Gradation of the aggregate used in a given bituminous mix is a primary factor. Gradation is allied to workability and density. Various engineering departments and other large engineering organizations have recommended densely graded mixes instead of open-graded aggregates. Well-graded materials produce the densest and, therefore, the most durable mixes requiring the minimum bitumen content for a satisfactory result. In this research, the aggregate gradations have been modified depending on the filler percentages.

3.3 Characterization of Materials

This segment will provide the general description of physical and chemical properties and the procedures of finding these characteristics of materials used in the mix design method to comprehend their functions in this research work.

3.3.1 Tests for Aggregates

Aggregate used in flexible pavement significantly influences pavement structure quality like functionality, reliability, and durability, significantly depending on its mechanical and physical properties. This section incorporates different aggregate tests to ensure the required quality of pavement practice as per BS: 812:1975 (PART 1, 2, 3) standards. The test designations of aggregate properties for both coarse and fine aggregates are mentioned in Table 3.2.

Table 3.2 Tests Specifications for Aggregates

Properties	Test Designation
Aggregate Impact Value	BS 812: Part 3
Aggregate Crushing Value	BS 812: Part 3
Ten Percent Fine Value	BS 812
Elongation and Flakiness Index	BS 812
Angularity Number	BS 812
Los Angeles Abrasion	AASHTO T96

3.3.1.1 Aggregate Impact Value

The test was adopted to measure the resistance to sudden impact or shock, which gives different responses to gradually applied compressive load. A sudden impact or shock can be occurred in the pavement due to the movement of vehicles on the road resulting in the breaking down of aggregate into smaller pieces. The sufficient strength required to resist their disintegration is known as toughness, assessed by the test. Aggregate with impact value (AIV) higher than 30 produces an inconsistent result. The AIV test was conducted following BS 812: Part 3 standard.

3.3.1.2 Aggregate Crushing Value

The ACV test is used to determine the aggregate crushing value of coarse aggregates using a compression test machine. The aggregates used in road construction should be strong enough to withstand crushing under traffic loads, or else they would produce smaller pieces not coated with a binder which would easily displace or loosen out, resulting in loss of the surface. The aggregate crushing value test gives a relative measure of the resistance of aggregates to crushing under a gradually applied compressive load. Aggregates with lower crushing value show a lower crushed fraction under load and would give a longer service life to the road and hence a more economical performance. An aggregate crushing value higher than 30 is considered inaccurate, and in such cases, the ten percent fines value should be determined instead. The ACV test was performed as per BS 812: Part 3 standard.

3.3.1.3 The Ten Percent Fines Value of Aggregate

The ten percent fines value test aims to determine the force required to produce 10% of fine material passing a specified sieve after crushing a prepared aggregate sample. It is applicable for both weak and robust aggregate and interprets the resistance of crushing subjected to loading. It is a compulsory test for aggregates with a crushing value greater than 30. The TFV test was conducted following BS 812: Part 3 standard.

3.3.1.4 Flakiness Index and Elongation Index of Aggregate

The aggregate shape is determined by the percentage of flaky and elongated particles contained in it. These particles tend to lock up with adjacent aggregate particles and resist reorientation into a denser configuration. Hence, they increase the compaction effort required to achieve a given density for a given HMA mixture. Again, flat and elongated particles are undesirable even for base coarse construction as they tend to break into smaller pieces along their weak, narrow dimension when subjected to compaction loading. The resulting higher number of fine particles fill existing void spaces and reduce the VMA, which can cause instability and durability problems. Both tests were performed following BS 812: Part 3 standard.

a) Flakiness Index

The scope of the test is to determine the flakiness of the coarse aggregate sample by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. Aggregate is classified as being flaky if it has a thickness (smallest dimension) of less than 0.6 of its nominal size. BS-1241 specifies that the flakiness index should not exceed 30%, irrespective of the aggregate size.

b) Elongation Index

The Elongation index is expressed as the percentage by mass of particles whose length (most significant dimension) is higher than 1.8 times their nominal size. According to BS-1241 maximum permitted Elongated index is 35, 40 or 45% for aggregate sizes 2 ½" – 2", 1 ½"– ¾" and ½"– 3/8" respectively.

3.3.1.5 Angularity Number of Aggregate

Angularity number test of aggregate gives the qualitative representation of the aggregate shape and is determined in terms of percentage of voids over voids in perfectly rounded aggregate (33%) after compacting in a prescribed manner. The more angular the aggregate is, the more is the angularity number.

For flexible pavement, angular aggregates with high angularity numbers are preferred because of high stability due to better interlocking and friction; however, it makes the mix less workable. This test also ensures that the resulting HMA mixture will be resistant to deformation under repeated loads and have improved durability. The value of the angularity number ranges from 0 to about 12. The test was conducted following the BS 812 standard test procedure.

3.3.1.6 Los Angeles Abrasion Test of Aggregate

The Los Angeles Abrasion (LAA) test is an empirical test that measures toughness and abrasion resistance of aggregate such as crushing, degradation and disintegration by use of standard steel balls, which when mixed with aggregates and rotated in a drum for some specified time for a specific number of revolutions also causes an impact on aggregates. The LAA test was performed according to AASHTO T 96 in this study.

Aggregates not adequately resistant to abrasion may cause premature structural failure, a loss of skid resistance, and excessive dust during HMA production, resulting in possible environmental problems and mixture control problems.

A higher LAA value indicates a softer aggregate, while a smaller value indicates a harder aggregate. According to AASHTO T 96, the coarse aggregate should have percentage wear by the LAA not more than 40% and 50% for base and sub-base correspondingly. Even though 0% of LAA will provide an excellent hard surface, its friction coefficient will be too high to damage the tires severely.

Figure 3.2 (a) Sample measuring for testing (b) Labeling for the certain test (c) Pycnometer for specific gravity test of fine aggregates (d) Coarse aggregates were soaked for achieving SSD condition (e) Aggregate impact value test (f) Tamping with rod in different layers (g) Compression testing machine for ACV, TFV tests (h) Los Angeles Abrasion test

3.3.2 Tests for Bitumen

It is recognized that compatibility and stability of bituminous pavement are essential aspects of bitumen binder quality, which is very difficult to specify effectively as the characteristic varies with temperature. This sub-section will evaluate some of its unique properties as per standard test methods with proper temperature control.

3.3.2.1 Penetration of Bituminous Material

Penetration determines the hardness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will vertically penetrate in 5 seconds, in a sample of bitumen maintained at a temperature of 25 degrees Celsius. Penetration value was determined using an empirical test method following AASHTO: T 49 standard.

The penetration test generally measures consistency. Higher values of penetration indicate having softer consistency. In warmer regions, lower penetration grades are preferred to avoid softening, whereas higher penetration grades are used in colder regions to prevent excessive brittleness. In Bangladesh, 60/70 penetration grade is regarded as appropriate for road construction, where 60 and 70 represent the minimum and maximum penetration value, respectively.

3.3.2.2 Flash and Fire Points of Bituminous Material

The flash and fire points test (Cleveland Open Cup Tester) was conducted by following AASHTO: T 48 method in this study. It is a safety test that indicates the maximum temperature to which the bitumen can be safely heated. As bituminous materials are mainly hydrocarbons, they give rise to volatile at high temperatures, and these volatiles catch fire, causing a flash, which is very hazardous.

The flashpoint is the lowest temperature at which the application of test flame causes the vapours from the material to momentarily catch fire in the form of a flash under specified test conditions. Again, the fire point is the lowest temperature at which the evolved vapours will ignite and burn at least for 5 seconds.

3.3.2.3 Ductility of Bituminous Material

The ductility value of the bituminous material was determined as per AASHTO: T 51 in this research. Ductile films are formed around the aggregates by a bitumen binder for the flexible pavement to improve the physical interlocking of the aggregates. Binder material having insufficient ductility gets cracked when exposed to temperature or repeated traffic loads, and it provides a pervious pavement surface. The ductility of a bituminous material is measured by the distance in cm to which it will elongate before breaking when two ends of a briquette specimen of the material are pulled apart at a specified speed and a specified temperature. Ductility of a minimum of 100 cm is generally specified for bituminous construction.

3.3.2.4 Solubility of Bituminous Material

The solubility test is generally used to detect contamination in bitumen content. The main test principle is to determine the degree of solubility in trichloroethylene or 1, 1, 1 trichloroethylene of bitumen having little or no mineral matter. The test was performed as per AASTHO: T 44 in this study.

3.3.2.5 Loss on Heating of Oil and Asphaltic Compound

This test was performed by following AASTHO: T179, which mainly aims to simulate the hardening process that a bituminous binder undergoes during construction and determines the combined effects of heat and air on a thin film of bitumen in terms of loss of mass excluding water. For pavement operation, bitumen more than 1% loss in weight is not allowed.

3.3.2.6 Softening Point of Bituminous Material

The softening point is a consistency test for semi-solid bituminous material using the ring-ball apparatus that is defined as the mean of the temperatures at which the bitumen disks soften and sag downwards a distance of 25 mm under the weight of a 3.5-g steel ball. This test was performed by following AASTHO: T 53 standard.

A higher softening point indicates lower temperature susceptibility and is preferred in hot climates. The softening point should be higher than the hottest day temperature, which is anticipated in that area; otherwise, bitumen may sufficiently soften and result in bleeding and developing rut.

3.3.2.7 Specific Gravity of Bituminous Material

This test covers the determination of the specific gravity of semi-solid bituminous material. Specific gravity is used to detect the presence of contaminants in petroleum products. Bituminous material has a specific gravity in the range of 1.01 to 1.05. If bitumen contains mineral impurities, the specific gravity will be higher, which also exhibits a higher boiling point. The AASTHO-T 43 test method was followed.

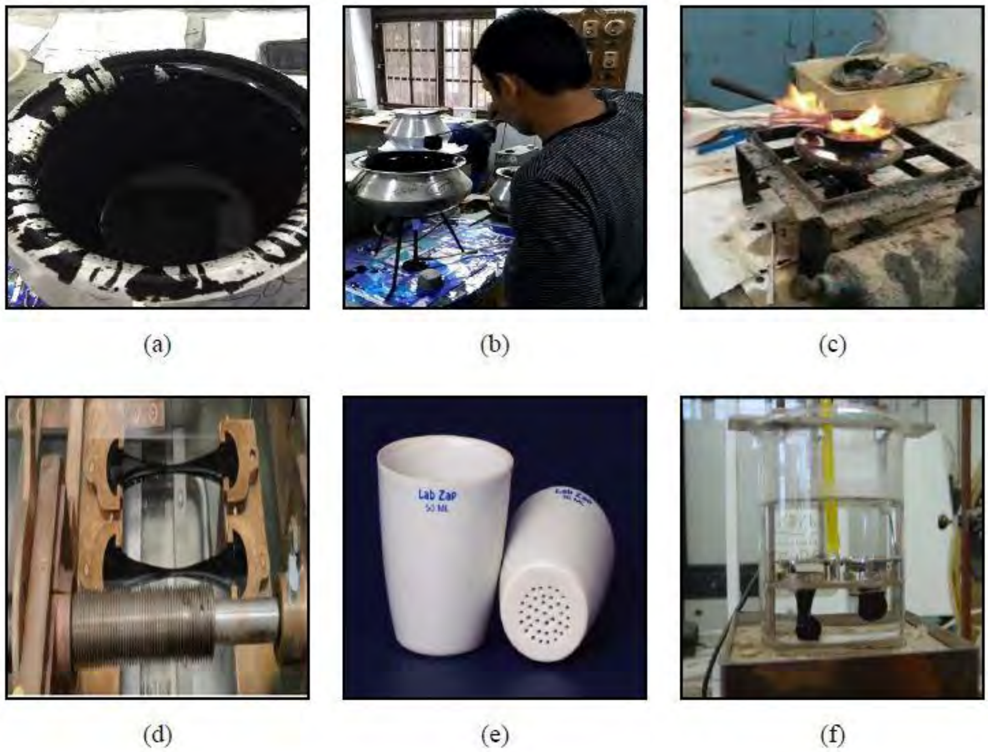


Figure 3.3 (a) Raw bitumen (b) Bitumen heated in burner before testing (c) Flash and fire point testing (d) Ductility testing of bitumen (e) Gooch crucible for solubility testing (f) Ring and Ball apparatus for softening point determination

3.3.3 Tests for Mineral Filler

Medical waste incineration fly ash and stone dust were used as mineral fillers in the mix design. This sub-section will illustrate some tests performed on filler material to analyze its engineering properties as the characteristics and performance of bituminous pavement depend on filler size, shape, surface area, surface texture, and other physiochemical properties.

3.3.3.1 Sample Collection

Fly ash sample was collected from the medical waste treatment facility operated by the PRISM Bangladesh Foundation owned a landfill site at Matuail, Dhaka. It is the only medical waste management program where the medical waste from different health care facilities from Dhaka is received, and after separation, chemical disinfection, shredding, autoclaving, they are taken into the incinerators.

There are two incinerators where fly ash is generated as products of the burning of medical waste. The incinerators have a total capacity of 135 kg/hour, which leads to the two rotary kiln systems of 60 kg/hour each. Fly ash sample was collected from the trash bins at the landfill site where incinerated fly ash was dumped.

3.3.3.2 Preparation of Fly Ash Sample

The methodology proposed by Tang et al. (2016) was adopted to process the sample. Fly ash samples were dried in the oven for 24 hours to ensure accurate quality during the experiment.

Subsequently, they are cooled to room temperature. After cooling, the samples were passed through the series of BS standard test sieves (#4, #8, #16, #30, #50, #100, and #200) using a mechanical sieve shaker. The portion of the sample passing through the #200 sieve (75 microns) was used in the asphalt mixtures as mineral filler in this study. Figure 3.4 shows the flow chart of the preparation.

Figure 3.4 Flow chart of fly ash filler preparation

3.3.3.3 Preparation of Stone Dust Sample

The stone dust filler was collected from the local market. After collecting the sample, it was stored in a place of low humidity and oven-dried for 24 hours. Then it was sieved through BS #200 sieve, and the passing samples that were passed through the #200 sieve were used as mineral filler and kept in an air-tight container.

(a) (b)

Figure 3.5 Prepared mineral filler samples (a) medical waste incineration fly ash (b) stone dust filler

3.3.3.4 Specific Gravity Test

The specific gravity of fly ash filler from medical waste incineration was determined using ASTM C 188-95 standard test method. Moreover, the ASTM D854-02 standard test procedure was adopted to determine the specific gravity of stone dust filler.

3.3.3.5 Toxicity Characteristic Leaching Procedure

The toxicity and leachability tests were carried out to ensure the environmental compatibility of the ash to be used as a filler material. Toxicity Characteristic Leaching Procedure (TCLP) test of the ash samples was carried out according to USEPA 1311 method. In the TCLP test, dried samples are ground and passed through a 9.5 mm standard sieve. An acetic acid solution (0.57% v/v) was added to samples at a constant liquid and solid ratio (20:1). The pH of the extraction fluid was 2.88 ± 0.05. After 18 h rotating with the rotary mixture at 30 ± 2 rpm, the leachate was filtered with 0.45 μm pore size filter paper and analyzed for As, Cd, Cr, Cu, Hg, Ni, Pb and Zn using Atomic Absorption Spectroscopy (AAS) (Shimadzu AA 6800).

3.3.3.6 X-Ray Fluorescence

The chemical composition of MWIFA and SD fillers was determined using X-Ray Fluorescence (XRF) in Glass and Ceramic Engineering Department, BUET. Energydispersive X-ray fluorescence technology provides one of the most straightforward, accurate, and economical analytical methods for determining the elemental composition of many types of materials.

It was first air-dried in a clean place for the sample preparation, then was grounded to break down aggregates. The preliminary ground sample was then subdivided by using quartering. The sample obtained in such a way was ground again into fine powder to yield an acceptable number of particles of each heterogeneous material component. After that, it was sieved through a sieve of 60 µm size, and the oversize was ground again until no grains more than 60 µm were left. For XRF measurements, the sample was additionally pulverized, homogenized, and pressed into a pellet with the binder. Usually, chromatographic cellulose, boric acid, or starch were used as a binder in a proportion of 1:10 by weight. For the emission-transmission method, a 150 or 200 mg pellet was prepared (25 mm diameter). A pallet made from ash and a binder was used for the XRF spectrophotometer (Shimadzu XRF-1800).

3.3.3.7 X-Ray Diffraction

X-Ray Diffraction (XRD) is a non-destructive test method used to analyze the structure of crystalline materials and reveals chemical composition information applicable to crystalline and non-crystalline materials. X-ray diffraction is also helpful in evaluating minerals, polymers, corrosion products, and unknown materials.

This test method is performed by directing an x-ray beam at a sample and measuring the scattered intensity as a function of the outgoing direction. Once the beam is separated, the scatter, also called a diffraction pattern, indicates the crystalline structure of the sample. The Rietveld refinement technique is then used to characterize the crystal structure, which most likely provided the observed pattern.

In most cases, the samples analyzed at elements are analyzed by powder diffraction using samples prepared as finely ground powders. For determination of XRD, a few tenths of a gram of the material were obtained as pure as possible and was crushed to a fine powder (less than ten µm), in a fluid to minimize inducing extra strain (surface energy) that would offset peak positions and to randomize orientation. Then the sample was packed into a sample holder and was sent for examination to the XRD instrument (MAXIma_X XRD-7000) and its associated software (X-ray Diffractometer).

3.3.3.8 Scanning Electron Microscope

Scanning Electron Microscopy (SEM) is a test process that scans a sample with an electron beam to produce magnified images that reveal information about external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample for analysis**.** Areas ranging from approximately 1 cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques (magnification ranging from 20X to approximately 30,000X, a spatial resolution of 50 to 100 nm). For assessment, the internal structures of MWIFA and SD samples were analyzed. The sample preparation was minimal, depending on the nature of the sample and the data required. First, powdered samples (10µm) were positioned on the SEM chamber accompanying carbon tape to prevent charge build-up on electrically insulating samples. Then samples were studied to an SEM (JEOL JSM-6490, USA). Consequently, photographs were obtained at an accelerating voltage of 5.0 kV with a magnification of 2000X.

3.4 Marshall Mix Design

Bruce Marshall of the Mississippi Highway Department developed the fundamental concepts of the Marshall mix design method in 1939. The Marshall method attempts to determine an optimum bitumen content at the desired density that meets minimum stability and range of flow values (White 1985). Firstly, aggregates are prepared and blended to make samples adopting a selected particle size distribution. Initially, mix design samples are prepared with outlined binder content. These specimens are then compacted by applying blows depending on expected traffic. The purpose of performing tests on compacted mixes is to determine the properties (bulk density, air voids, stability, and flow) at service conditions. A set of Marshall Test specimens would be prepared and tested in the laboratory for standard Marshall mix design. A volumetric analysis would also be conducted on the test specimens. The properties include; characteristics under load. If the mix fails to meet the specified mix design criteria, the mix is reformulated, and the tests are repeated until an acceptable design is established.

3.4.1 Preparation of Test Specimens

Sample preparation is started after special quality requirements of materials are ensured. It is necessary to check all the materials to be used in the experiment to meet the physical requirements of the project specifications to ensure that the aggregate blend combinations meet the gradation requirements of the project specifications. For void analysis, the bulk specific gravity of all aggregates and the specific gravity of asphalt is determined. Tests needed to satisfy material requirements are already explained in Article 3.2, and as there is no hard and fast rule for batch mixing of aggregates in (Asphalt Institute MS-2 2014), experience-based laboratory techniques will be applied here. The standard specimen shape used in the Marshall test specimen is cylindrical with 63.5 mm height and 101.7 mm dia. In this experiment, a total of 71 specimens were prepared following the specified procedure of heating, mixing, and compacting the asphalt-aggregate mixtures.

Three different types of specimens, namely (a) reference specimen using conventional filler (stone abrasion dust), (b) modified specimen using varying proportions of medical waste incineration fly ash waste as filler and (c) control specimen without any filler, were prepared for testing. Using 0.5% increment of binder content the specimen are prepared with 4.0%, 4.5%, 5.0%, 5.5%, and 6.0% of binder for each percentage of filler.

The two main features of the Marshall method are a density-void analysis and a stability-flow test of the compacted test specimen. Again, to find the design asphalt content for a particular blend or gradation of aggregates, a series of test samples must be prepared for a range of different asphalt content so that the test data curves represent well-defined relationships. Generally, a 0.5% increase of bitumen content is used for a different mixer. It is wiser to choose the asphalt content increments so that at least two asphalt contents remain above and another two asphalt contents remain under the expected design asphalt content. To prepare mixtures, the amount of each aggregate size fraction required to produce the required gradation and a batch that will result in a compacted 63.5 ± 1.27 mm (2.5 ± 0.05 in.) height specimen was weighed into separate pans for each test specimen, and it was ensured that each batch was about 1.2 kg (2.7 lb.) in weight. Trial specimens were composed to check whether the specimens would fall into the height limit or not, and in this case, specimens were within limits, so no aggregate mass adjustment was needed. Here laboratory standard aggregates were collected and separated. These initially separated and homogeneously mixed aggregates and asphalt binders were used throughout the test. For the aggregate preparation, stone chips were dried to a constant temperature at 105ºC to 110ºC (220ºF to 230ºF) and separated by dry sieving into the desired size fraction. According to the estimated calculation for each sieve size, sieving was done, and sieved stone chips were stacked in a specified place in the laboratory to avoid mixing with other test materials. These standard size fractions were used for mould preparation-

i. 25.0 to 19.0 mm (1 to ¾ in.)
ii. 19.0 to 9.5 mm (¾ to 3/8 in.)
iii. 9.5 to 4.75 mm (3/8 in. to No. 4)
iv. 4.75 to 2.36 mm (No. 4 to No. 8)
v. 2.36 to 0.3 mm (No. 8 to No. 50)
vi. 0.3 to 0.075 mm (No. 50 to No. 200)
vii. 0.075 mm to Pan

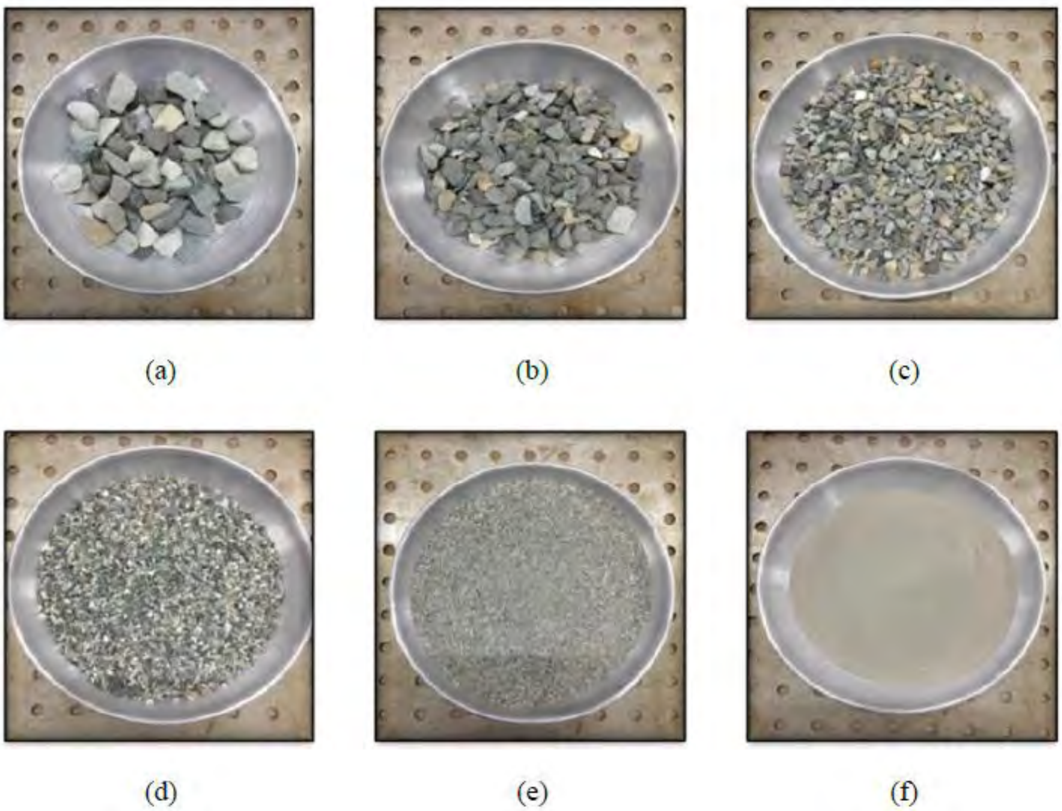


Figure 3.6 Material size fraction a) 1 to ¾ in. b) ¾ to 3/8 in. c) 3/8 in. to No. 4 d) No. 4 to No. 8 e) No. 8 to No. 50 f) No. 50 to No. 200

3.4.1.1 Number of Specimens

The Marshall method recommends three specimens for each aggregate and binder content combination. One specimen for each aggregate and binder content combination is prepared to minimize the laboratory work in this study.

During sample preparation and testing, the specification of the mix design method is strictly and carefully followed to get representative results. Though one specimen for each combination of aggregate and binder content was tested, the results were found to be very consistent.

Total 55 specimens were prepared with 4.0%, 4.5%, 5.0%, 5.5%, and 6.0% of bitumen content for each percentage of medical waste incineration fly ash and stone dust fillers for Marshall stability and flow tests.

In this research work, MWIFA was varied as 0%, 2%, 4%, 6%, 8%, and 10% in the specimens. Conventional filler was also varied 2%,4%,6%,8% and 10%. Additionally, six more specimens with MWIFA filler variation of 0%, 2%, 4%, 6%, 8%, and 10% with respective optimum bitumen content were prepared for the Marshall immersion and TCLP tests. The same was followed for SD filler. For the dutch tank leaching test, only five specimens with MWIFA filler variation of 2%, 4%, 6%, 8%, and 10% with respective optimum bitumen content were prepared.

3.4.1.2 Mixing and Compaction Temperature

Mixing and compaction temperature depend on the viscosity of the binder. In this experiment, mixing and compaction were carried out at 150°C and 140 °C, respectively.

3.4.1.3 Preparation of Mould and Hammer

The mould assembly and the face of the compaction hammer were cleaned thoroughly. They were heated in a water bath to a temperature between 95°C and 150°C. The filter paper was used in the bottom of the mould before the mixture was placed in the mould.

3.4.1.4 Preparation of Mixture

A half-litre bitumen container was heated in an oven to the ideal mixing temperature (150°C ± 5°C). Mixing was done in a mechanical mixer with a bowl capacity of approximately four litres. The mixing bowl, mechanical stirrers, and any other implements used in the mixing procedure were pre-heated to the mixing temperature. The heated aggregate sample was placed in the mixing bowl and thoroughly mixed using a trowel. A crater was formed in the center of the mixed aggregate. Then, the required weight of bitumen was poured into it. The mixture was then produced with a uniform distribution of bitumen by using the mechanical mixer.

3.4.1.5 Packing the Mould

The entire batch was placed in the prepared mould. Filter papers were used at the bottom of the mould. The mixture was spaded vigorously with a heated spatula 15 times around the perimeter and ten times over the interior. The surface was smoothened to a slightly rounded shape. Before compaction, the mix temperature is immediately maintained within the compaction temperature (145°C±3°C).

3.4.1.6 Compaction of Specimen

Another paper disc was placed on the top surface of the mix. The mould, along with the base plate and filling collar, were transferred to the Marshall Compaction apparatus. For the medium traffic design category, 50 numbers of blows per face were applied by a hammer using a free fall of 457 mm (18 in.) according to ASTM D6926, maintaining the axis of the compaction hammer as nearly perpendicular to the base of the mould assembly as possible. After compaction, the mould assembly was removed and dismantled to reverse the mould.

Figure 3.7 Placing the mixture in the mould

The equipment was reassembled, and the same number of blows was applied to the reversed specimen. The mould assembly was then placed on a bench where the base plate, filling collar, and paper discs were removed. The mould and the specimen were allowed to cool in the air. Thus, no deformation of the specimen during extraction by using an extrusion jack. The compacted briquette was labelled and allowed to cool to room temperature, ready for testing the following day. The whole procedure was then done on the remaining specimens.

Figure 3.8 Specimen preparation steps: (a) Weighing batch mix (b) Heating in oven (c) Batch mix in mechanical mixer (d) Bitumen measuring (e) Compaction machine (f) Compacted mould

3.4.2 Testing of Specimens

The Marshall tests were conducted on compacted specimens to find stability and flow values of different mixes. For volumetric analysis of compacted specimens, it was necessary to know the bulk and maximum specific gravity of the mixes. The maximum specific gravity of each specimen is determined after completing the stability and flow test.

3.4.2.1 Determination of bulk specific gravity

After cooling down, the height of the newly compacted specimen was measured, and ASTM D2726 completed the bulk specific gravity determination- Bulk Specific Gravity of Compacted Bituminous Mixture Using Saturated Surface-Dry Specimens.

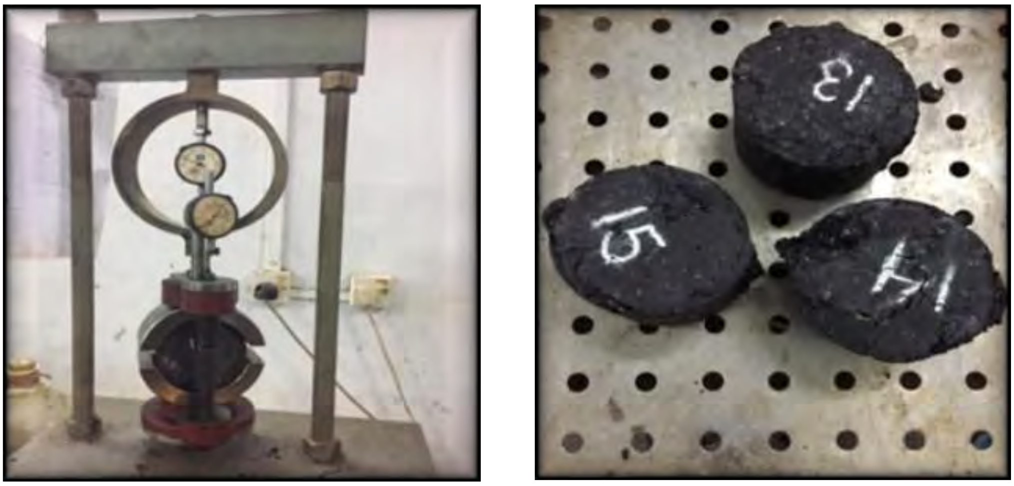
3.4.2.2 Stability and Flow Test

After the bulk-specific gravity testing, the Marshall stability and flow test can be done. Specimen height was determined by using a slide calliper. In the water bath, the specimen was immersed at 60ºC ± 1ºC (140ºF ± 1.8ºF) for 30 to 40 minutes before testing, and it was confirmed that the water bath was at least 150 mm (6 in.) deep having a perforated false bottom or a shelf for suspending the specimen at least 50 mm (2 in.) above the bottom of the bath. A device with a proving ring and flow meter was used as Marshall testing machine was similar to a compression testing device according to ASTM D6927 where flow meter was placed over the marked guide rod and set to zero while holding it firmly against the upper segment of the testing head during load application. The inside surfaces of the testing heads were cleaned thoroughly, and the temperature of the testing heads was maintained between 21.1ºC to 37.8ºC (70ºF and 100ºF) by using a water bath when required.

Figure 3.9 Prepared Marshall samples in the water bath

Then guide rods are lubricated by thin oil film so that the upper test head will slide freely without binding. It was ensured that the dial indicator was firmly fixed and showed zero for the no-load condition. The test specimen was removed, and the surface of the specimen was dried with a towel while the testing apparatus was ready. Then the test specimen was placed in the lower testing head and centered as well as the upper testing head was fitted into position and centered on completing the loading device assembly. Then the flow meter was placed over a marked guide rod as described above. The testing load was applied until failure at a constant deformation rate (51 mm or 2 in. per minute).

The point of failure was defined when maximum load reading was obtained, and the total force obtained in Newton (N) to promote failure was noted as the Marshall stability value of the specimen. While the stability test was in progress, the flow meter was held firmly in position over the guide rod and removed immediately when the load began to decrease. Reading was taken and recorded then where the flow value of the specimen is expressed in units of 0.25 mm (1/100 in.). The entire process of stability and flow measurements was completed within 30 seconds, just after the withdrawal of the specimen from the water bath.



(a) (b)

Figure 3.10 (a) Marshall stability and flow test arrangement mould in the testing machine (b) Deformed moulds after tests

3.4.2.3 Determination of Maximum Specific Gravity

ASTM D2041 determined the theoretical maximum specific gravity (Gmm) of the mix for one mixture prepared with the same aggregate and 5% binder content for each percentage of fly ash as filler. The mixture was weighed in air. Then it was placed in a container, and water was poured into submerging the sample sufficiently, and vacuum pressure was applied to remove the void from the mixes. Then the weight of the sample was taken in water. Maximum specific gravity was determined to calculate the air void of the mixes.

3.4.2.4 Density and Void Analysis

After completing the stability and flow test, a density and void analysis for each specimen are vital. The bulk specific gravity values for all test specimens of specific asphalt content were averaged, and the values obviously in error were not included while averaging. Further, the average unit weight for each asphalt content was determined by multiplying the average bulk specific gravity value with the unit weight of water (1000 kg/m3 [62.4 lb/cft). The theoretical maximum specific gravity of the mix (Gmm) was determined by ASTM D2041, as described in 3.4.2.3. An average value for the specific gravity of total aggregate (Gse) was calculated from these values. After that, this value was used to calculate the maximum specific gravity of mixtures with different asphalt content.

Using the effective (Gse) and bulk specific gravity (Gsb) of the total aggregate, the average bulk specific gravity of the compacted mix (Gmb), the specific gravity of the asphalt (Gb) and the maximum specific gravity of the mix specified in (c), the percent absorbed asphalt (Pba) by weight of dry aggregate, percent air voids (Va), percent voids filled with asphalt (VFA) and the percent voids in the mineral aggregate (VMA) were calculated.

3.4.2.5 Selection of an Optimum Asphalt Binder percentage

The optimum asphalt binder content was finally selected based on the combined results of Marshall stability and flow, density analysis, and void analysis. Optimum asphalt binder content was calculated by following the procedure. (Sutradhar et al. 2015; Kumar et al. 2019).

The following graphs were plotted for filler percentage and checked whether the graphs follow the reasonably consistent plot pattern and trends or not as specified in Asphalt Manual.

a) Asphalt binder content vs. density
b) Asphalt binder content vs. Marshall stability
c) Asphalt binder content vs. flow
d) Asphalt binder content vs. air voids
e) Asphalt binder content vs. VMA
f) Asphalt binder content vs. VFA

For a percentage of filler, bitumen content at maximum stability, maximum bulk density, and at designed air voids, 4% were determined from the plotted graphs.

From the average of these values, the optimum bitumen content of that percentage of filler was obtained. All the property values at this optimum asphalt binder content must satisfy the Marshall mix design criteria shown in Table 3.4 by referring to the plots.

If all were within specification, then that optimum asphalt binder content was acceptable. Otherwise, if any of these properties were outside the specification range, the mixture would have to be redesigned. Then the steps were followed for each percentage of fly ash to obtain their respective optimum bitumen contents.

Table 3.3 Minimum Percent Voids in Mineral Aggregate

Nominal Maximum Particle Size[1, 2]		Minimum VMA, percent Design Air Voids, Percent[3]		
Mm	in.	3.0	4.0	5.0
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19.0	20.0	21.0
4.75	No. 4	16.0	17.0	18.0
9.5	3⁄8	14.0	15.0	16.0
12.5	1⁄2	13.0	14.0	15.0
19	3⁄4	12.0	13.0	14.0
25	1	11.0	12.0	13.0
37.5	1.5	10.0	11.0	12.0
50	2	9.5	10.5	11.5
63	2.5	9.0	10.0	11.0

[1]Standard Specification for Wire Cloth Sieves for Testing Purposes, ASTM E 11 (AASHTO M 92)

[2]The nominal maximum particle size is one size larger than the first sieve to retain more than 10 percent.

[3]Interpolate minimum voids in the mineral aggregate (VMA) for design air void values between those listed.

Table 3.4 Marshall Mix Design Criteria

Marshall Method Criteria[1]	Light Traffic[3] Surface and Base		Medium Traffic[3] Surface and Base		Heavy Traffic[3] Surface and Base	
	Min	Max	Min	Max	Min	Max
Compaction, number of blows each end of the specimen	35		50		75	
Stability[2], N (lb.)	3336 (750)	-	5338 (1200)	-	8600 (1800)	-
Flow[2, 4, 5] 0.25 mm (0.01 in.)	8	18	8	16	8	14
Percent Air Voids[7]	3	5	3	5	3	5
Percent Voids in Mineral Aggregate (VMA)[6]	See Table 3.3					
Percent Voids Filled with Asphalt (VFA)	70	80	65	78	65	75

[1]All criteria, not just stability value alone, must be considered in designing an asphalt paving mix.

[2] Hot mix asphalt bases that do not meet these criteria when tested at 60°C (140°F) are satisfactory if they meet the criteria when tested at 38°C (100°F) and are placed 100 mm (4 inches) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climatic conditions.

[3] Traffic classifications

Light Traffic conditions resulting in a 20-year Design ESAL < 10^4

Medium Traffic conditions resulting in a 20-year Design ESAL between 10^4 and 10^6

Heavy Traffic conditions resulting in a 20-year Design ESAL > 10^6

[4] The flow value refers to the point where the load begins to decrease. When an automatic recording device is used, the flow should be corrected, as shown in section 7.3.3.3.

[5]The flow criteria were established for neat asphalts. The flow criteria are often exceeded when polymer-modified or rubber-modified binders are used. Therefore, the upper limit of the flow criteria should be waived when polymer-modified or rubber-modified binders are used.

[6]Percent voids in the mineral aggregate are to be calculated on the basis of the ASTM bulk specific gravity for the aggregate, as discussed in chapter 5.

[7]Percent air voids should be targeted at 4 percent. This may be slightly adjusted if needed to meet the other Marshall criteria.

3.5 Mechanical Marshall Immersion test

Mechanical Marshall immersion tests were performed to investigate the deviations in the properties of hot bituminous mixtures under the effect of moisture. The methodology performed by Akbulut et al. (2012) was adopted to conduct the test. The tests were carried out for the specimens containing two types of fillers such as MWIFA and SD. Filler varied in ratios of 0%, 2%, 4%, 6%, 8%, and 10% in the mixes. Those specimens were produced using the respective optimum bitumen contents and cured in a water bath at 60°C for 48 hours. After the curing, a Marshall stability test was performed on the specimens.

3.6 Calculation of Optimum Filler Percentage

Using more or less filler than usual in hot bituminous mixtures could have adverse effects on the performance of the mix, so determining the optimum filler ratio of mix is relatively essential (Meheri et al. 2007). In order to calculate the optimum filler ratio, critical bituminous hot mixture properties were assessed. These are maximum stability, lowest Marshall stability lost, maximum density, and lowest percentage of void in the hot bituminous mixture. The optimum filler content was calculated from the average of the filler contents relative to these identified properties, using the following equation (Akbulut et al. 2012). Akbulut et al. (2012) used the filler content value corresponding to maximum stiffness modulus at 40◦C along with the other four values to calculate optimum filler content. In this research work, Indirect tensile tests on the paving mixtures could not be performed to determine the stiffness modulus due to laboratory limitations. For this reason, the filler content value corresponding to maximum stiffness was not considered in the determination of optimum filler content for both fillers in this study.

$$\textit{Optimum Filler Content (\%)} = \frac{(Fs+Fmi+Fd+Fv)}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

here,

F_s is the filler content corresponding to maximum stability;

F_{mi} is the filler content corresponding to minimum stability loss (determined from the Marshall mechanical immersion test);

F_d is the filler content corresponding to maximum unit weight;

F_v is the filler content corresponding to the minimum percentage of voids in mineral aggregate

3.7 Leaching Test

Two leaching extraction tests were performed on the Marshall specimens containing 0%, 2%, 4%, 6%, 8%, and 10% fly ash with respective optimum bitumen contents to assess stabilized medical waste incineration fly ash in asphalt paving mixture. The toxicity characteristic leaching procedure (TCLP) was conducted according to USEPA 1311 method. The Netherlands tank leaching test was performed following NEN 7345 guidelines, and the extracts were analyzed for heavy metals using AAS (Shimadzu AA-7000).

3.7.1 TCLP Test

The Toxicity Characteristics Leaching Procedure (TCLP) test is designed to identify wastes that are likely to leach hazardous concentrations of particular toxic constituents into the groundwater. During the TCLP test, constituents are extracted from the waste to simulate leaching actions in landfills. The waste is identified as hazardous if the concentration of the toxic constituents exceeds the regulatory limit.

Test Sample

The TCLP test was done for two types of samples.

1) Prepared sample, which is described in section 3.4.

2) Marshall samples containing 0%, 2%, 4%, 6%, 8%, and 10% fly ash with respective optimum bitumen contents.

Method of the test

Both samples were dried in an oven at 105°C until constant weight, lightly ground for homogenization and crushed to a particle size smaller than 9.5mm. TCLP provides two choices of buffered acidic extraction fluids (acetic acids) based on the alkalinity and the buffering capacity of the ash. Extraction fluid A had a pH of 4.93 ± 0.05, and extraction fluid B had a pH of 2.88 ± 0.05. In this study, extraction fluid B was used.

The extraction fluid was added to a zero-headspace extractor (ZHE) at a liquid-solid ratio of 20:1, and the samples were agitated with a National Bureau of Standards (NBS) rotary tumbler for 18 hours. After 18 hours of rotating with the rotary mixture at 30 ± 2 rpm, the leachate was filtered with 0.45 µm pore size filter paper and analyzed for As, Cd, Cr, Cu, Hg, Ni, Pb and Zn using Atomic Absorption Spectroscopy (AAS) (Shimadzu AA 6800).

(a) (b)

Figure 3.11 a) TCLP test setup (b) Powdered samples from moulded specimens

3.7.2 Dutch Tank Leaching Test

This standard diffusion test method determines the leaching of inorganic components from building materials and monolithic waste and stabilized waste materials under laboratory conditions. According to Kosson et al. (1996), asphalt compacted with ash should undertake to leach controlled by solid-state diffusion.

A diffusion leaching test should be used to evaluate leaching in diffusion-controlled conditions. The dutch tank leaching test was carried out in eight successive leaching steps of specified time-length, giving eight leachate fractions followed by Juel et al. (2017) and Todorovic et al. (2003).

Test Sample

Total five Marshall samples containing 2%, 4%, 6%, 8%, and 10% medical waste incineration fly ash filler with respective optimum bitumen contents were prepared for this experiment.

Method of the test

Volumes, surface areas and masses of Marshall samples were measured to carry out the tests. Each sample was put in a polyethylene container and filled with acidified water (HNO_3 at pH = 4).

The volume of extractant fluid in each recipient was approximately five times the sample volume, and the sample was completely submerged with the fluid level not less than 5 cm high from the top of the sample. For each sample, eight extractions were done. The leachate is removed and replaced with fresh extractant fluid eight times after 0.25, 1, 2.25, 4, 9, 16, 36, and 64 days as per NEN 7345. Leachate obtained from each extraction was filtered through a 0.45 m filter and analyzed using AAS (Shimadzu AA 7000) for the specified heavy metals. Equation (3.2) was used to compute the leachability of each pollutant (heavy metals) at the i^{th} extraction.

$$Ei = \frac{(Ci - Co)V}{1000A} \quad \text{……………………………………………………………………… (3.2)}$$

here,

Ei = leachability of a pollutant at the i-th extraction (mg/m^2);

Ci = pollutant concentration at the i-th extraction (mg/l);

Co = pollutant concentration in the blank (mg/l);

V = volume of extractant agent (L);

A = surface area of the sample (m^2);

Figure 3.12 An arrangement of the leaching test (according to NEN 7345) being carried out in the laboratory with MWIFA incorporated Marshall samples

After eight extractions, equation (3.3) was used to compute the leachability, E, for the targeted heavy metals.

$$E = \sum_{i=1}^{8} Ei \quad \text{………………………………………...…………...…………………….... (3.3)}$$

3.8 Overview

In this study, a structured approach was followed to inspect the utilization of medical waste incineration fly ash as filler in asphalt pavement. The Marshall mix design method was adopted to determine the optimum bitumen content for each percentage of filler. Mix designs were carried out for both types of specimens containing medical waste incineration of fly ash and stone abrasion dust as fillers. An optimum fly ash content was established from the properties of the mix designs. TCLP and Dutch Tank Leaching (NEN 7345) tests using acidic were conducted for leaching analysis of the solidified asphalt fly ash matrix.

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the laboratory experiments carried out to characterize the raw materials (bitumen, aggregates, and fly ash from medical waste incineration) and to determine the optimum bitumen ratios of asphalt paving mixes containing filler ratios of 0%, 2%, 4%, 6%, 8%, and 10%. This chapter also finds out the optimum filler percentage for both fillers (MWIFA and stone dust as conventional filler) and examines the leaching test results of fly ash and fly ash incorporated Marshall hot mix asphalt samples.

4.2 Characterization of Raw materials

4.2.1 Bitumen

In our study, all Marshall samples were prepared using the identical bitumen binder collected from the BUET Transportation Laboratory. Considering the weather pattern and traffic management system of Bangladesh, 60/70 grade bitumen was used in this study. Asi et al. (2005) used 60/70 grade bitumen to assess fly ash performance from Jordanian oil shale in asphalt mixes. Bitumen 60/70 grade was used to study the effect of different types of fly ash in asphalt mixtures on properties of asphalt mixtures by Sola et al. (2011) and Mirković et al. (2019). The properties summary of bitumen used in the asphalt mix with AASHTO standard designations is given in Table 4.1. All of the properties except solubility and fire point are within the standard ranges. The presence of a tiny amount of impurities may account for the high fire point value and the low solubility value.

4.2.2 Aggregates

Aggregates, both coarse and fine, were collected from the local market, and the properties of the aggregates have been tested in the BUET Transportation Laboratory, Dhaka, Bangladesh. The aggregate gradation, which was used in this study, is shown in Table 4.2. While increasing filler percentage, the same proportion of fine aggregate was replaced by filler material to conserve the specified total aggregate amount, and the batch weights of combined aggregates are given in Table 4.3.

Table 4.1 Properties of Bitumen

Properties	AASHTO Designation	Obtained values	AASHTO M 20-70 specifications for 60/70 penetration bitumen [a]	
			min	max
Penetration at 25˚C (0.1mm)	T49	61	60	70
Flash Point (˚C)	T48	295	232	-
Fire Point (˚C)	T48	345	300	320
Ductility at 25 ˚C (cm)	T51	100+	100	-
Solubility in Trichloroethylene (%)	T44	97.8	99.0	-
Loss on Heating (%)	T179	0.06	-	0.8
Softening Point (˚C)	T53	49	48	56
Specific Gravity at 25˚C	T43	1.023	1.01	1.026

[a] AASHTO M 20-70, (2004). Standard Specification for Penetration Graded Asphalt Cement. American Association of State and Highway Transportation Officials.

Several standard laboratory tests were conducted on the aggregates to determine physical properties. Table 4.4 illustrates the obtained results of the aggregates properties tests, test specifications, and standard limits. All test results depict that those aggregates are stable and durable as their associated results values are within the specification limit. Los Angeles abrasion and aggregate impact tests show that aggregates abrasion loss is lesser than the specified, and so the aggregates provide well resistance to the abrasion effects on the exposed hot bituminous mixture due to traffic and rolling process. Kar et al. (2014), Sutradhar et al. (2015) and Rahman et al. (2012) used durable and stable aggregates. The AIV values and abrasion losses were suitable to the specification limit in asphalt mixtures.

Table 4.2 Gradation of Combined Aggregate

Sieve Size	Percent Passing (%)	Specification Criteria (%) [a]
1 inch (25 mm)	100	100
3/4 inch (19 mm)	95	90-100
3/8 inch (9.5 mm)	68	56-80
No. 4 (4.75 mm)	50	35-65
No. 8 (2.36 mm)	35-38	23-49
No. 50 (0.3 mm)	9-17	5-19
N0. 200 (0.075 mm)	0-10	2-8

[a] ASTM D351501 Standard Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures. For dense mixtures, mix designation: D-4.

Table 4.3 Batch Weight of Combined Aggregates

Sieve Size	Filler Percentages					
	0%	2%	4%	6%	8%	10%
	Batch Weight (gm)					
1 inch (25 mm)	0	0	0	0	0	0
3/4 inch (19 mm)	57.75	57.75	57.75	57.75	57.75	57.75
3/8 inch (9.5 mm)	311.85	311.85	311.85	311.85	311.85	311.85
No. 4 (4.75 mm)	207.9	207.9	207.9	207.9	207.9	207.9
No. 8 (2.36 mm)	173.25	173.25	161.7	161.7	150.15	138.6
No. 50 (0.3 mm)	300.3	288.75	277.2	265.65	254.1	242.55
N0. 200 (0.075 mm)	103.95	92.4	92.4	80.85	80.85	80.85
Mineral Filler	0	23.1	46.2	69.3	92.4	115.5

Table 4.4 Properties of Aggregates

Properties	Test Designation	Obtained Results	Standard values [a] [b]
Aggregate Impact Value (%)	BS 812: Part 3	28	< 30 [a]
Aggregate Crushing Value (%)	BS 812: Part 3	17	< 30 [b]
Ten Percent Fine Value (KN)	BS 812	130	min 100 [a]
Flakiness Index (%)	BS 812	26	< 30 [a]
Elongation Index (%)	BS 812	29	< 30 [a]
Angularity Number	BS 812	11	0-12 [a]
Los Angeles Abrasion (%)	AASHTO T96	31	< 35 [b]
Specific Gravity (CA)	AASHTO -T85	2.72	-
Specific Gravity (FA)	AASHTO -T84	2.6	-

[a] No, A., (1992). Specification for aggregates from natural sources for concrete. BS 882.

[b] RHD (2011). Standard specifications for pavement work, Government of the People's Republic of Bangladesh Ministry of Communications Roads and Highways Department, Bangladesh.

4.2.3 Mineral Filler

In this research, the effect of medical waste incineration fly ash as mineral filler in asphalt mixes has been determined. The properties of control bituminous mixes with stone dust filler, the locally conventional filler, have also been studied for comparison. Two specific gravity tests were performed to determine the specific gravity of both fillers according to the procedures specified by ASTM and given in Table 4.5.

Table 4.5 Physical properties of Fillers

Filler	Properties	Specification	Result
MWIFA	Specific Gravity (gm/cm^3)	ASTM C 188	2.57
SD	Specific Gravity (gm/cm^3)	ASTM D 854	2.79

Several tests were conducted to examine the chemical and physical properties of fly ash and stone dust. Table 4.6 presents the chemical composition of fly ash and stone dust obtained from XRF-Spectrometer analysis. The test results reveal that the investigated major elements of fly ash are CaO, SiO_2 and SO_3, while the major elements of stone dust are SiO_2, CaO, Al_2O_3, Fe_2O_3 and MgO. The presence of SiO_2, CaO, and Al_2O_3 in biomedical waste ash was stated by Rajor et al. (2012).

Table 4.6 Chemical Composition of Fly ash and Stone dust

Chemical Components (wt%)	Medical Waste Incineration Fly Ash (MWIFA)	Stone Dust (SD)
CaO	62.39	25.53
SiO_2	8.92	51.71
SO_3	5.92	0.61
Na_2O	5.35	0.10
TiO_2	3.73	0.79
Al_2O_3	3.73	6.17
MgO	2.65	5.50
ZnO	2.13	-
Fe_2O_3	1.75	6.11
P_2O_5	1.38	0.19
K_2O	1.19	2.16
NiO	0.50	-
Cr_2O_3	0.21	0.07
MnO	0.07	0.10
CuO	0.04	-
Br	0.03	-
ZrO_2	-	0.01
SrO	-	0.05

ASTM C 618-19 standards for fly ash classes are mentioned in Table 4.7. In the Fly ash from medical waste incineration, the ($SiO_2 + Al_2O_3 + Fe_2O_3$) content is 14.40%, less than 50%, and SiO_3 exceeds 5%. So, the fly ash cannot be considered as class F or Class C fly ash. According to Mirković et al. (2019), as the fly ash comprises a high content of CaO (62.39%), it can be used in asphalt mixtures, highly adhesive aggregates and bituminous binder to exhibit positive effects on mixture stability.

Table 4.7 ASTM Classification Fly Ash

			Class F	Class C
Chemical Requirements	$SiO_2 + Al_2O_3 + Fe_2O_3$	min%	70	50
	SiO_3	max%	5	5

The external morphology (texture) and shape of the particle were analyzed for both fillers using Scanning Electronic Microscopy (SEM) and shown in Figure 4.1 and Figure 4.2. The SEM images of MWIFA reveal that the particles have irregular shapes and assorted sizes. The surface texture of MWIFA seems rough, and the internal space between particles can be visibly detected. In contrast, the particles of stone dust have angular and prismatic shapes with smooth surface textures.

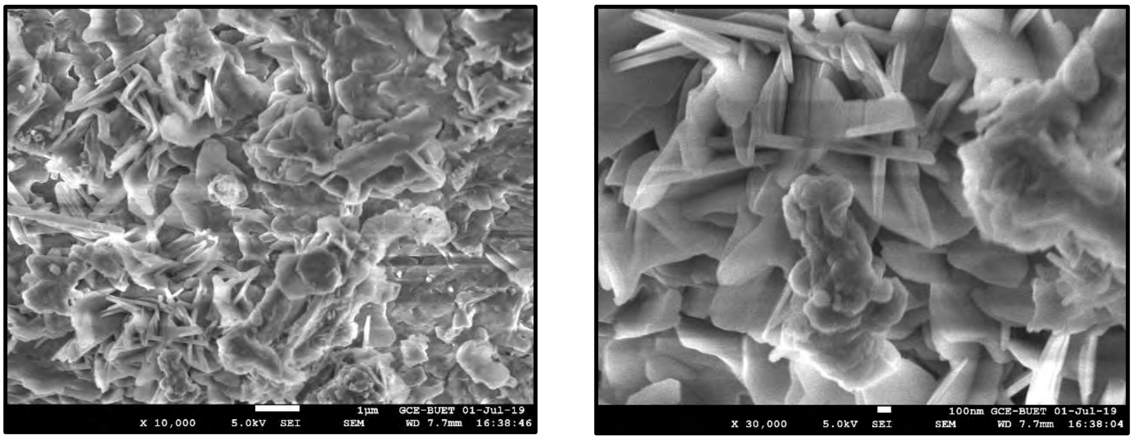


Figure 4.1 SEM images of fly ash filler from medical waste incineration

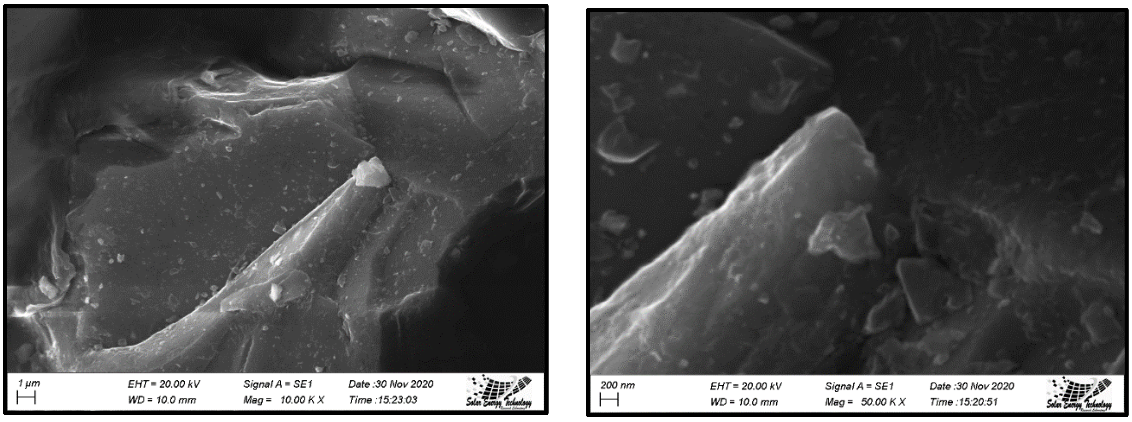


Figure 4.2 SEM images of stone dust filler

4.3 Marshall Test Results

The aim of performing Marshall tests is to evaluate the performances of the modified asphalt paving mixes at their service life. A comparative analysis of mixes with MWIFA and SD fillers is illustrated in this section. All the parameters of the Marshall test, such as stability, flow, and void ratios, will be considered a measurement index. All Marshall test results and associated details for MWIFA and SD fillers are provided in the Appendix B section at the end of this thesis report.

4.3.1 Unit Weight

Unit weight increases surface contact and inter-particle friction in a compacted paving mixture, contributing to higher stability and pavement strength. Pavement with low density (usually defined as less than 92 percent of Gmm) and interconnected air voids cause premature pavement distresses such as premature oxidation ageing, enlarged cracking, rutting, structure weakening, ravelling and stripping.

Figure 4.3 and Figure 4.4 depict the relationship between unit weight (lb/cft) with the asphalt content in the bituminous mixes for MWIFA filler and SD filler, respectively. Filler varies in ratios of 0%, 2%, 4%, 6%, 8%, and 10% in the bituminous mixes. The unit weight values increase with the increase of asphalt content for both fillers except for 6% SD and 8% MWIFA filler percentages. The increasing bitumen content fills the voids, henceforth increasing unit weight in the mix (Sutradhar et al. 2015).

Çelik (2008) found that the unit weight values increased with increased asphalt content in bituminous mixes for 6%, 7%, and 8% fly ash filler percentages. However, for 2% and 6% MWIFA filler percentages, unit weight values increase initially with the increase of asphalt content, reach a maximum, then decrease. Fly ash enters into the voids between sand particles, thus raising the density and unit weight initially. After a certain fly ash content, the relatively larger fly ash thrusts out the sand particles while forming more voids within itself, decreasing the unit weight (Mazumdar and Rao 1993). The 4% and 8% SD filler percentages also follow the same trend. Similar results have been depicted in the studies of utilizing fly ash, stone dust, brick dust and cement as fillers in the hot bituminous mixes (Kar et al. 2014; Sutradhar et al. 2015; Rahman et al. 2012). On the other hand, the unit weight values of 8% MWIFA and 6% SD fillers decrease with increasing asphalt content, reach a minimum, then increase with the increase of asphalt content.

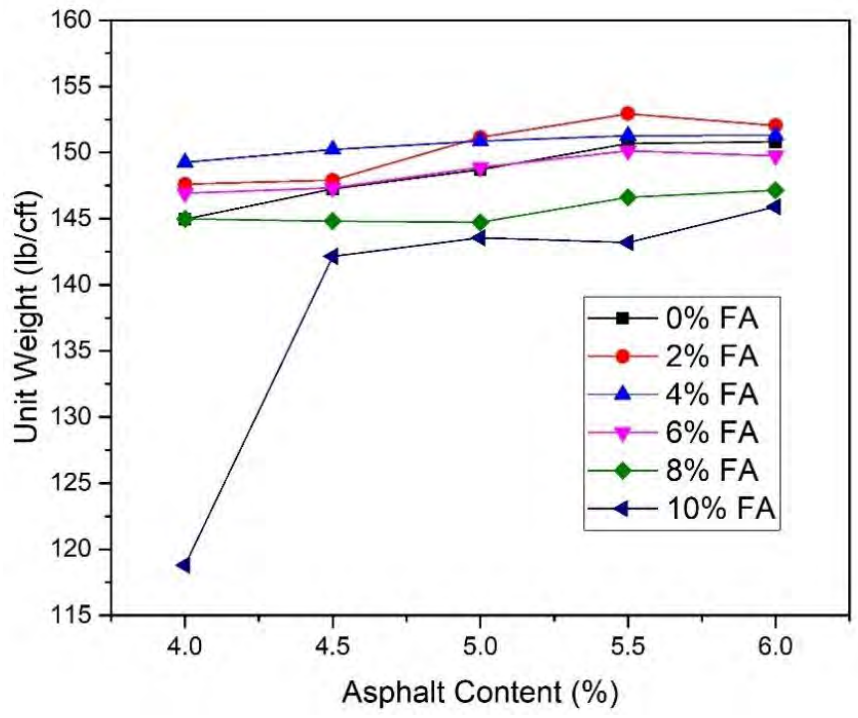


Figure 4.3 Relationship between unit weight and asphalt content for medical waste incineration fly ash filler

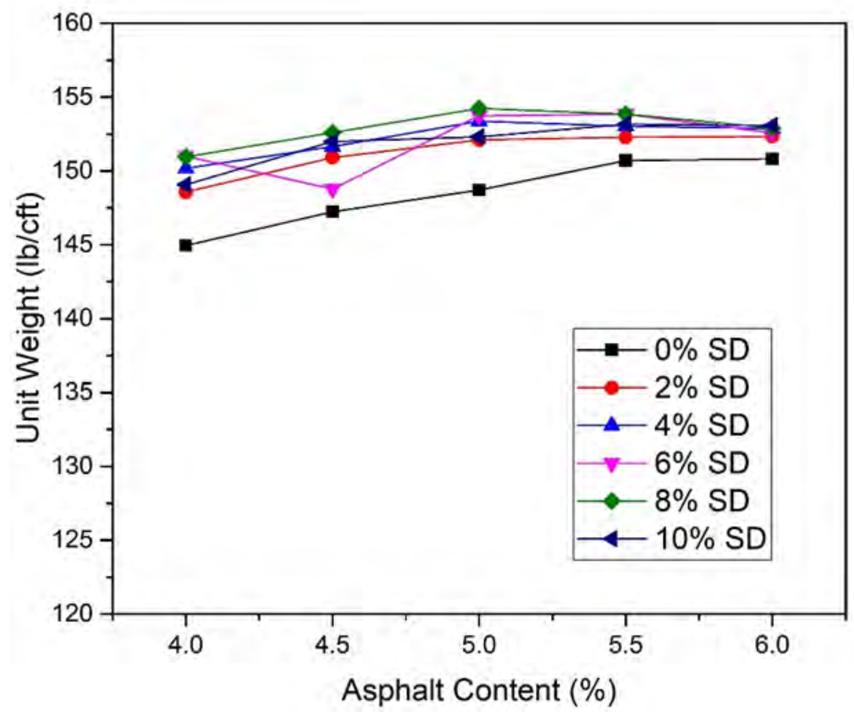


Figure 4.4 Relationship between unit weight and asphalt content for stone dust filler

The effect of both filler types and the change on the maximum unit weight of compacted mixes is shown in Figure 4.5. At maximum density, hot bituminous mixes exhibit desired permeability properties, durability against deterioration and the slow ageing process (Chen et al. 2011; Kandhal et al. 1998). The maximum unit weight of MWIFA filler decreases with the increase of filler percentages, and the peak is found at 2%. Jony et al. (2011) found the peak at 4% with a similar decreasing pattern for waste glass powder filler in their investigation and stated the sliding action of particles and the specific gravity of fillers as reasons behind these results. For SD filler percentages, the maximum unit values increase with filler percentages but slightly decrease after showing a peak at 8% filler percentage. Saltan et al. (2015) found maximum unit weight at 9% filler percentage for cullet and domestic glass dust fillers. The maximum unit weight values of SD filler are higher than the MWIFA filler except for the 2% MWIFA percentage.

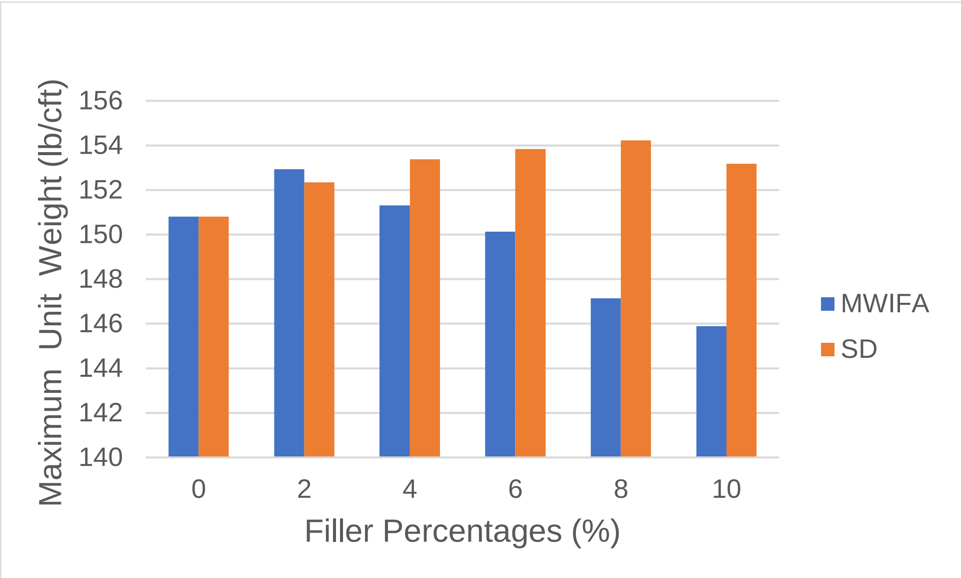


Figure 4.5 Effect of medical waste incineration fly ash and stone dust fillers on maximum unit weight

4.3.2 Stability

The stability of an asphalt mixture pavement resists shoving and rutting under loads (traffic). Stability determines the strength against normal and shear stresses from the traffic in bituminous hot mixture pavements (Akbulut et al. 2012). The relationship between the stability values and bitumen contents for fly ash and stone dust fillers is depicted in Figures 4.6 and 4.7, respectively.

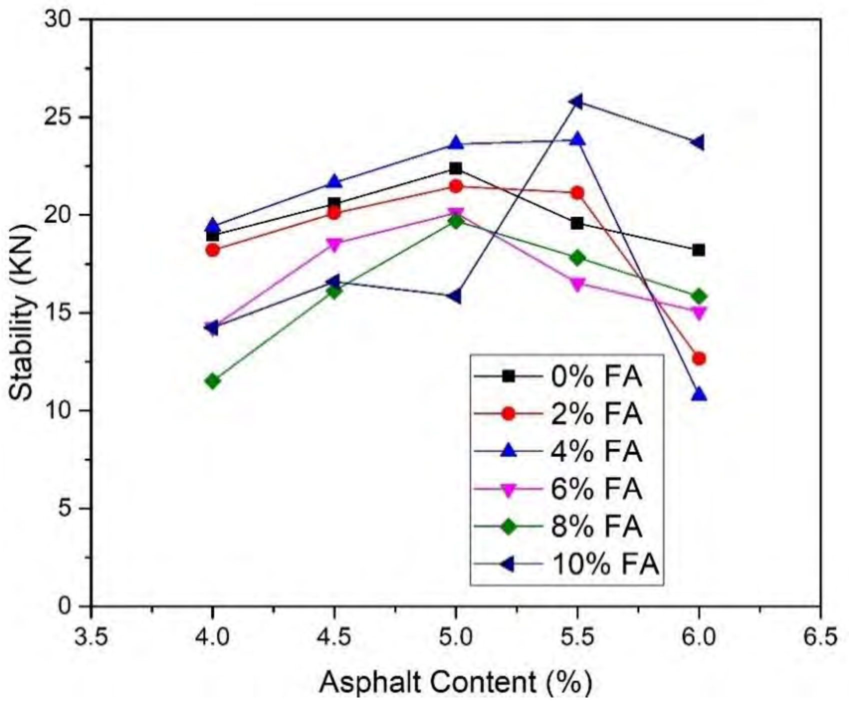


Figure 4.6 Relationship between Marshall stability and asphalt content for medical waste incineration fly ash filler

Figure 4.6 illustrates that the stability values of 0%, 2%, 4%, 6%, and 8% MWIFA filler increase with bitumen content, and after reaching a peak, decrease with the increase of bitumen content. The 6% SD filler percentage follows the same pattern in Figure 4.7. Sutradhar et al. (2015), Kar et al. (2014), Saltan et al. (2015), Jony et al. (2011) and Rahman et al. (2012) found similar stability results for their respective fillers investigations in asphalt mixes. Mistry and Roy (2016) found that Marshall stability rose with fly ash content by up to 6% of fly ash and then fell for higher fly ash contents. However, for 10% MWIFA filler, stability values go up at 4.5% bitumen content and decrease at 5%, increase afterwards by reaching a peak at 5.5% bitumen content and then slightly down at 6%. The 2% and 8% SD filler percentages go along with the same graph pattern. For 4% and 10% SD, stability values decrease with increasing asphalt binder content without showing a peak. Uzun et al. (2012) found that the stability values for andesite waste as mineral filler in asphaltic concrete mixtures decreased with increased asphalt content and did not show any peak. Though the stability graphs of MWIFA and SD fillers follow different trends, all the Marshall stability values meet the minimum Marshall mix design criteria of 5.338 kN stability value recommended by the Asphalt Institute.

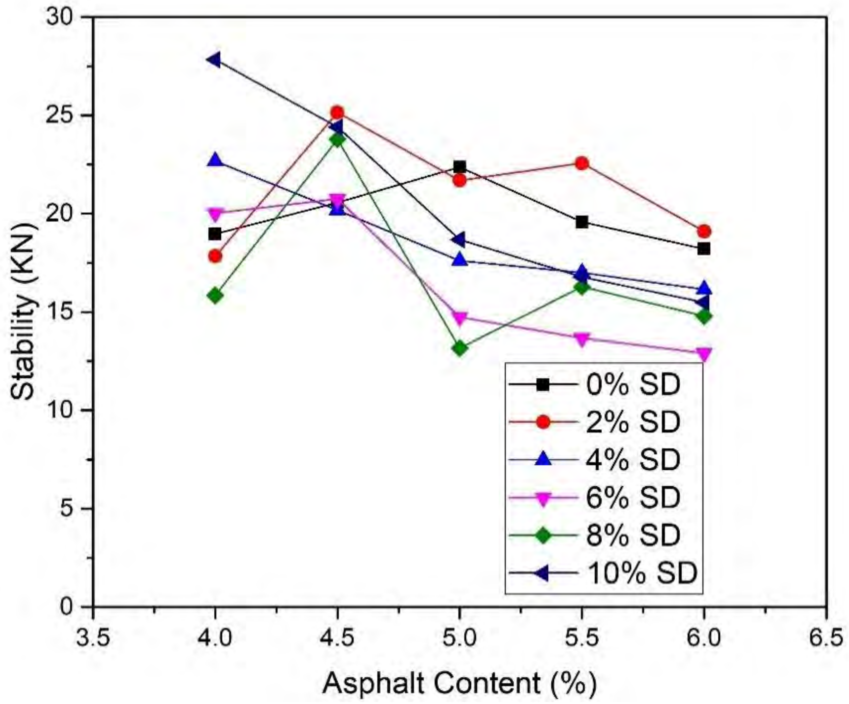


Figure 4.7 Relationship between Marshall stability and asphalt content for stone dust filler

Figure 4.8 indicates the nature of variation of the maximum Marshall stability values with varying MWIFA and SD fillers content mixes. Maximum stability values of mixes with 0%, 2%, 4%, 6%, 8%, and 10% MWIFA filler additive are found to be 22.37 kN, 21.47 kN, 23.82 kN, 20.11 kN, 19.70 kN, and 25.80 kN respectively. Maximum stability values of mixes with 2%, 4%, 6%, 8%, and 10% stone dust filler are 25.15 kN, 22.68 kN, 20.75 kN, 23.78 kN, and 27.82 kN, respectively. For MWIFA filler, maximum stability increases at 4%, then decrease up to 8% and afterward exhibits the highest stability by increasing to 25.80 kN at 10%. Fly ash is finer than sand, and so it goes into the voids of sand, serves to interlock the voids of sand and serves to interlock the particles that cause the initial increase in stability values (Mazumdar and Rao 1993). For SD filler, maximum stability decreases up to 6%, then increases up to 10% and shows the highest stability of 27.82 kN at 10%. Jony et al. (2011) compared the stability values with the specification limits set by the ministry of Iraq in their study. Besides, they found the highest stability of ordinary portland cement, limestone powder and glass powder fillers at 10%, 7%, and 7%, respectively. The corresponding maximum stability values are 9.1 kN, 8.9 kN, and 9.6 kN, respectively. Çelik (2008) and Sargın et al. (2013) obtained the highest stability at 5% fly ash and 5% rice husk filler percentages, respectively. Androjic et al. (2013) found the maximum stability at the mixes with 3% fly ash additive in a similar investigation. The attained Marshall stability values of these studies were compared to their corresponding specification limits, and the obtained values were higher than the minimum criteria. The bitumen contents corresponding to maximum stability of the mixes with MWIFA filler are higher than the mixes containing SD as filler, and the maximum stability values of SD filler mixes are comparatively higher. It indicates that SD filler produces a more viscous asphalt cement mixture with lower bitumen content (Sutradhar et al. 2015).

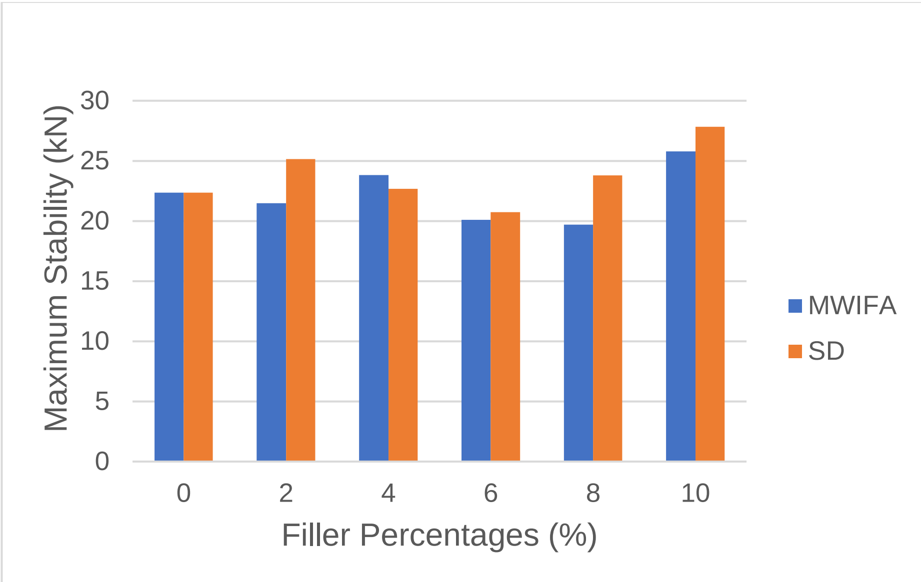


Figure 4.8 Effect of medical waste incineration fly ash and stone dust fillers on maximum stability

4.3.3 Flow

The flow value, which represents the plasticity and flexibility properties of bituminous mixtures, has an inverse linear relationship with internal friction (Saltan et al. 2015). Figure 4.9 and Figure 4.10 illustrate the relationship between the Marshall flow value and bitumen content varying MWIFA and SD fillers percentages, respectively. Both the figures show the non-linear relationship between the flow values and bitumen contents.

The flow values of 0% and 4% SD filler percentages increase initially at 4.5% bitumen content, decrease sharply up to 5.5 % and rise again at 6% bitumen percentage. The flow value of 2% MWIFA filler percentage increases with the rise of bitumen contents but slightly falls at 5% bitumen content. The flow values of 4% MWIFA and 10% SD fillers percentages increase with bitumen contents, but 10% SD filler shows an initial fall at 4.5% bitumen content. The flow values of 6% MWIFA and 8% SD filler percentages increase with bitumen content but fall at 6% bitumen content. The flow values of 2% and 6% SD fillers change irregularly with the bitumen percentages. Uzun and Terzi (2012), Sutradhar et al. (2015), Kar et al. (2014) and Çelik (2008) found the flow values increasing with the bitumen contents in their studies.

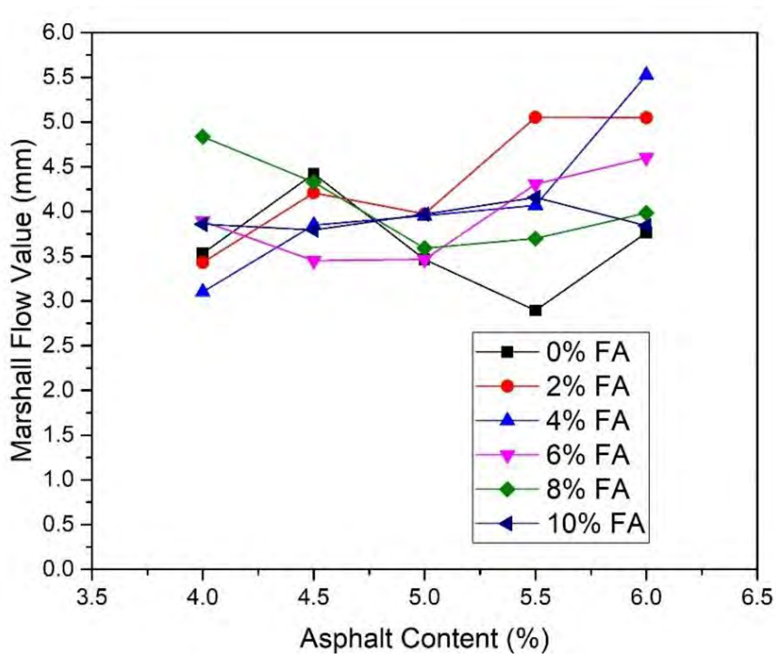


Figure 4.9 Relationship between Marshall flow value and asphalt content for medical waste incineration fly ash filler

The flow values of 8% MWIFA filler percentage decrease with bitumen content up to 5% and increase afterwards. The flow values of 10% MWIFA filler percentage decrease initially at 4.5% bitumen content then increase sharply up to 5.5% and fall again at 6% bitumen percentage. The decrease of flow values may be ascribed to the increased interlocking offered by fly ash particles, and the successive rise in flow values maybe because of the large surface area, resulting in insufficient coating (Mazumder and Rao 1993). Jony et al. (2011) found the value of flow for asphalt mixture with glass powder as filler decreased from 3 mm at 4% content to 2 mm at 7% and 10 % content due to the siliceous biases of glass powder. Nevertheless, reverse results were found in the OPC and limestone fillers. All the flow values are within 2.5 mm to 4.5 mm. Few flow values could not meet the Marshall mix design range, which is 2 mm to 4 mm recommended by the asphalt institute. Sargın et al. (2013) studied the rice husk ash (RHA) utilization using different proportions (4%, 5%, 6%, and 7%) as mineral filler in the hot mix asphalt and found all flow values within 2.26 mm to 7.53 mm.

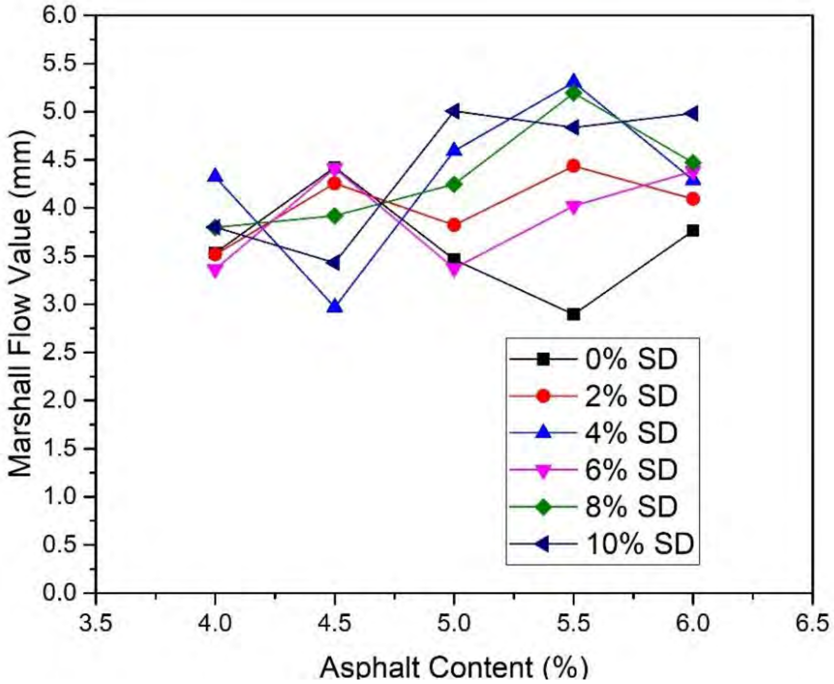


Figure 4.10 Relationship between Marshall flow value and asphalt content for stone dust filler

4.3.4 Air Voids

Air voids are small air spaces between bitumen-coated aggregate particles in the final compacted paving mix. A substantial percentage of air voids is necessary for all dense-graded mixes to prevent the pavement from flushing, shoving, and rutting. In general, the design air void level in a laboratory-compacted sample of HMA is 4 percent. A lower or higher design air void content may be specified for particular uses. Job specifications usually require that, for dense-graded mixes, pavement compaction achieve an air void content of less than 8 percent to minimize permeability.

Figure 4.11 and Figure 4.12 show the relationship between the percentage of air void and bitumen content in each mix configuration with MWIFA and stone dust fillers, respectively.

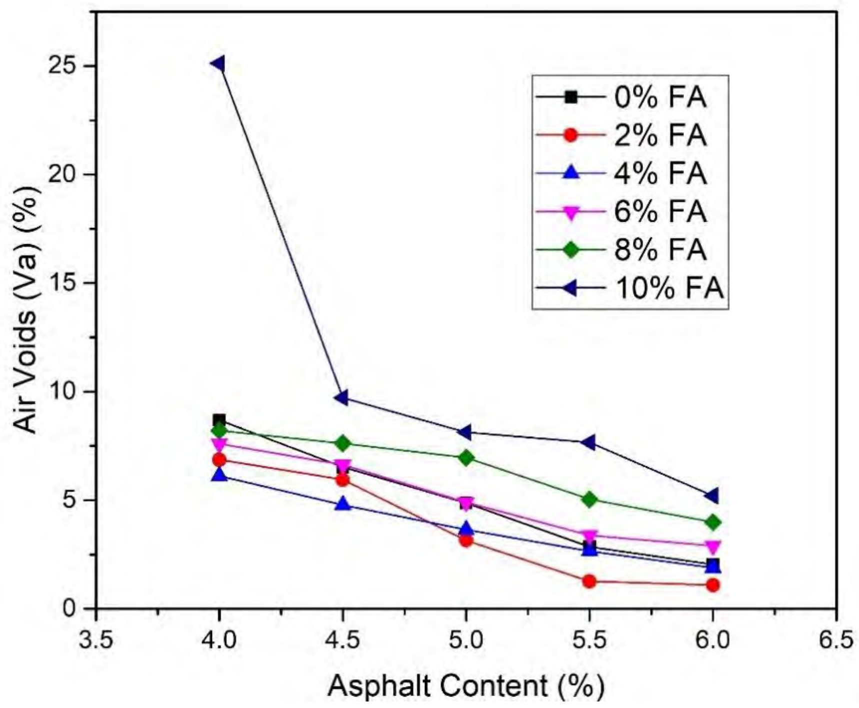


Figure 4.11 Relationship between air voids and asphalt content for medical waste incineration fly ash filler

The percentage of air voids decreases with the increase of bitumen contents for both fillers percentages. An initial increase at 4.5% bitumen ratio in air voids is found for 6% SD filler, but then the air voids values decrease afterwards with the increase of bitumen ratio. The increased bitumen content reduces air voids percentages by filling more voids in the paving mixture. Nayak and Mohanty (2020), Uzun and Terzi (2012), Kar et al. (2014), and Mazumdar and Rao (1993) found a similar decreasing trend of air voids values with increased bitumen content from their fly ash and stone dust as mineral filler in bituminous mixes studies. The addition of filler to hot bituminous mixtures eases the compensation of fine aggregates in the mix, and thus voids in the mixtures reduce with the increase of filler percentages (Sutradhar et al. 2015).

The air voids values for SD filler are lower than the MWIFA filler for each filler ratio at each respective bitumen content. This difference is maybe because SD filler provides a higher surface area that fills the voids more effectively than MWIFA (Kar et al. 2014, Sutradhar et al. 2015).

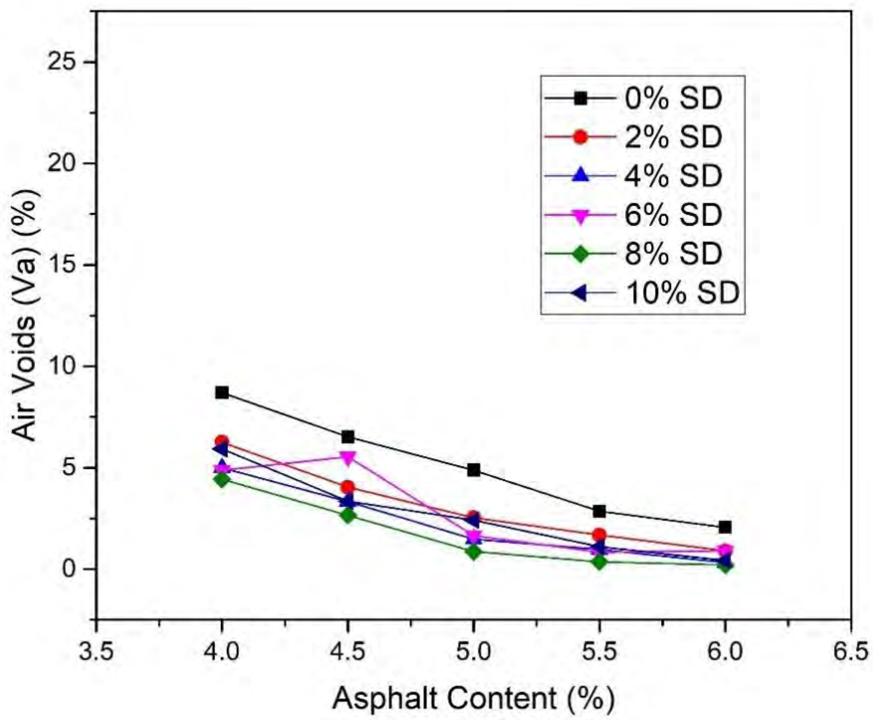


Figure 4.12 Relationship between air voids and asphalt content for stone dust filler

4.3.5 Voids in Mineral Aggregate

Voids in mineral aggregate are a vital parameter that affects the durability and fastening of aggregates to each other. Voids in the mineral aggregate (VMA) are the existing air-void spaces between the aggregate particles in a compacted paving mix, including spaces filled with asphalt.

Adequate VMA during mix design helps in establishing adequate film thickness without excessive asphalt bleeding or flushing (Uzun and Terzi 2012). An Adequate film thickness ensures durability in the mix (Chadbourn et al. 1999).

Figure 4.13 and Figure 4.14 depict the relationships between voids in mineral aggregate (%) and asphalt contents varying MWIFA and stone dust fillers percentages. All the VMA (%) values for both fillers meet the Marshall minimum design requirement for VMA recommended by Asphalt Institute.

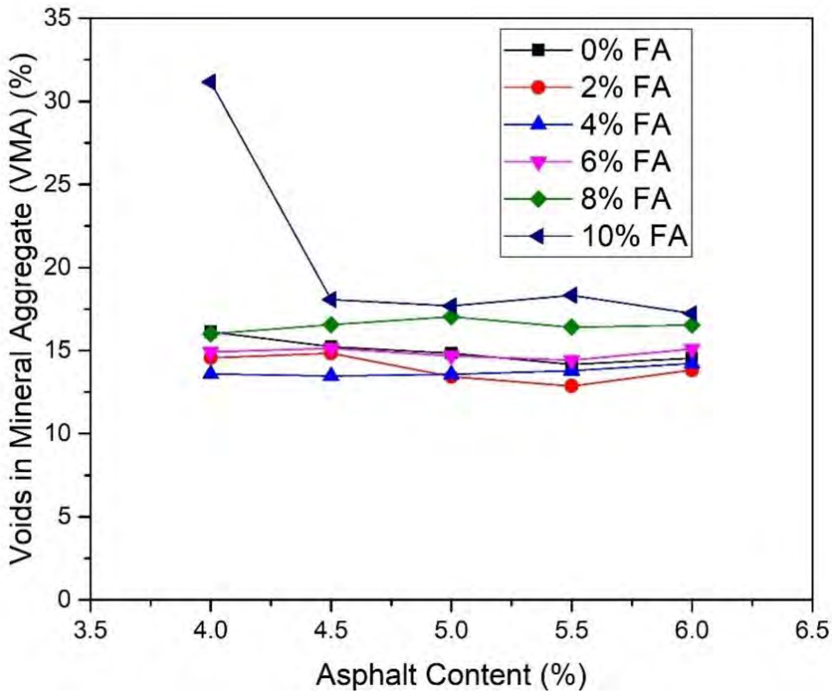


Figure 4.13 Relationship between voids in mineral aggregate and asphalt content for medical waste incineration fly ash filler

The VMA values decrease with increasing asphalt binder content, reach a minimum, increase for 0%, 4%, 10% of MWIFA and 2%, 4%, 8%, and 10% of SD fillers percentages. Previous studies found that %VMA value increases with an increase of bitumen content in paving mixture for various types of fly ashes and stone dust as mineral fillers (Çelik 2008; Jony et al. 2011; Uzun and Terzi, 2012; Kar et al. 2014; Sutradhar et al. 2015; Rahman et al. 2012).

VMA generally reduces to a minimum value because of the better compaction and rises as the aggregate begins to be pushed apart by the extra added bitumen content in the mix (AI MS-2 2014). However, for MWIFA filler, the VMA values initially rise at 4.5% AC for 2% and 6% filler contents, and the rise is shown at 5.0% AC for 8% filler percentage. Then, the VMA values fall minimum at 5.5% of AC for the earlier mentioned filler percentages and increase afterward. However, for the 6% SD filler percentage, the VMA values initially increase at 4.5% AC, then fall to the minimum at 5.0% of AC and increase afterward with bitumen content. Sargın et al. (2013) found similar %VMA results for Rice husk ash filler.

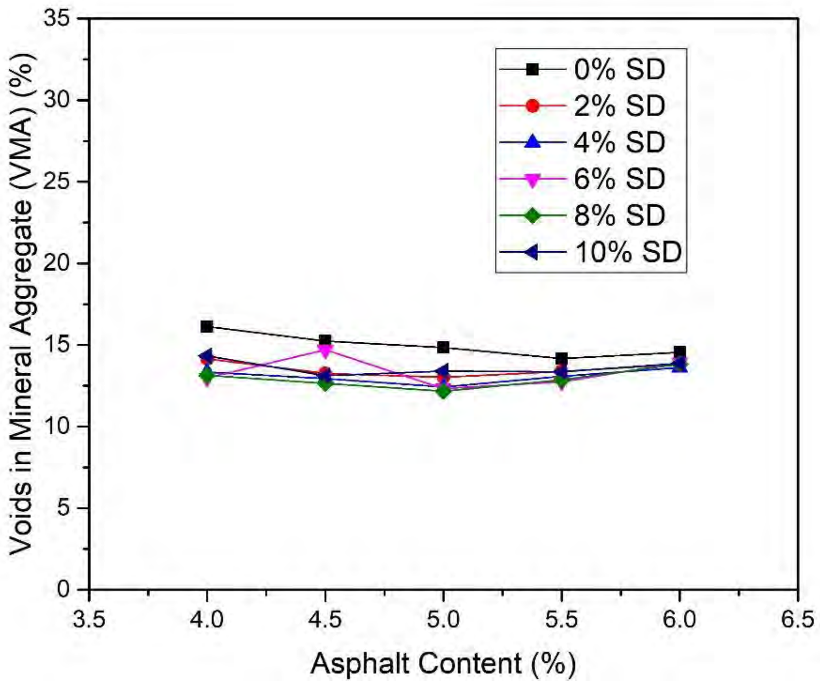


Figure 4.14 Relationship between voids in mineral aggregate and asphalt content for stone dust filler

4.3.6 Voids Filled with Asphalt

The voids filled with asphalt regulate the plasticity, durability, and friction coefficient of the bituminous mixtures and provide a final bitumen film around the aggregate particle. The objective of VFA analysis is to limit maximum levels of VMA and substantially maximum levels of asphalt percentage. VFA also controls the allowable air void content in compacted mixes.

The relationships between voids in mineral aggregate and asphalt content affected by variations in MWIFA and stone dust fillers percentages are shown in Figure 4.15 and Figure 4.16, respectively.

The %VFA values of compacted mixtures increase with bitumen contents for both filler percentages. Previous studies found that %VFA value increases with an increase of bitumen content in paving mixture for various types of fly ashes and stone dust as mineral fillers (Çelik 2008; Jony et al. 2011; Uzun and Terzi, 2012; Saltan et al. 2015; Kar et al. 2014; Sutradhar et al. 2015).

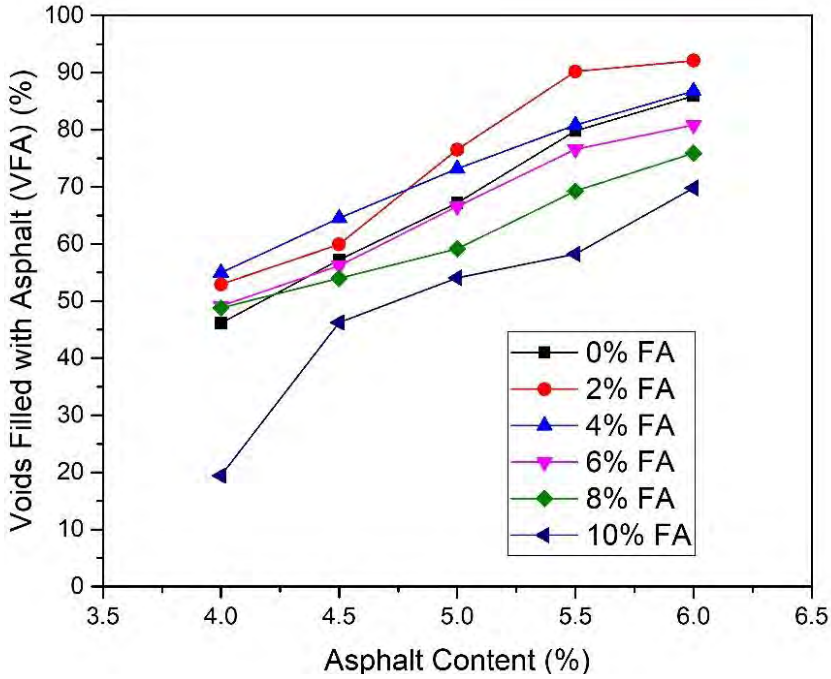


Figure 4.15 Relationship between voids filled with asphalt and asphalt content for medical waste incineration fly ash filler

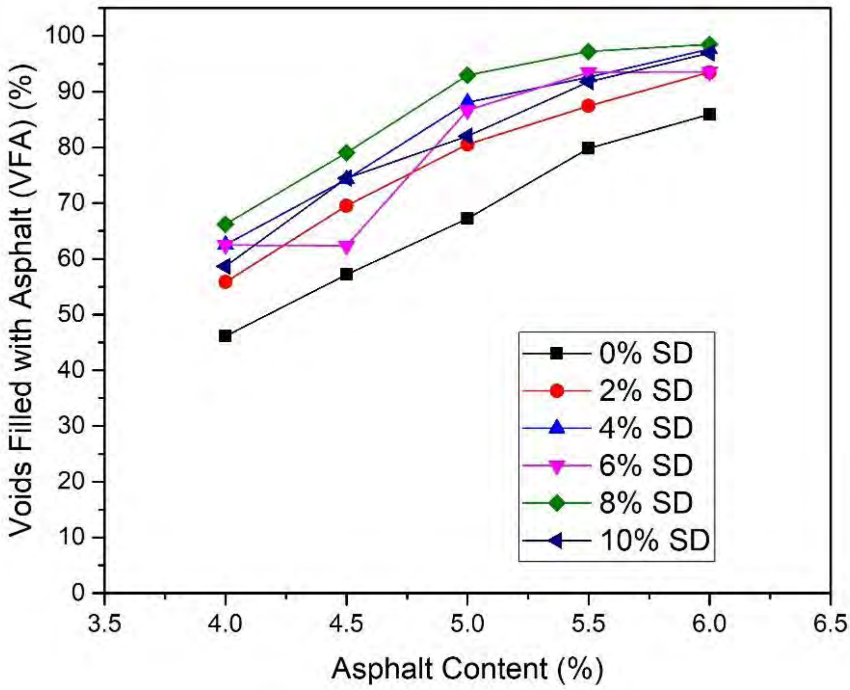


Figure 4.16 Relationship between voids filled with asphalt and asphalt content for stone dust filler

4.4 Optimum Bitumen Content

Optimum bitumen contents (OBC) are calculated for each MWIFA and stone dust fillers percentages and shown in Figure 4.17. For 0%, 2%, 4%, 6%, 8%, and 10% MWIFA filler contents, the optimum bitumen ratios are found 5.22%, 4.85%, 4.84%, 5.3%, 5.99%, and 6.25%, respectively. All the optimum bitumen content levels are within 4.9% to 6.5%, the standard limit of Roads and Highway, Bangladesh. Furthermore, optimum bitumen contents are 4.51%, 4.3%, 4.7%, 4.12%, and 4.37% for the stone dust filler content percentages of 2%, 4%, 6%, 8%, and 10% respectively. Rahman et al. (2012) found optimum bitumen contents for brick dust, cement and stone dust as mineral fillers in bituminous mixes are 6.20%, 6.10%, and 6.30%, respectively. Kar et al. (2014) found that optimum bitumen for fly ash from a coal-based thermal plant filler was 5.20% in the paving mix.

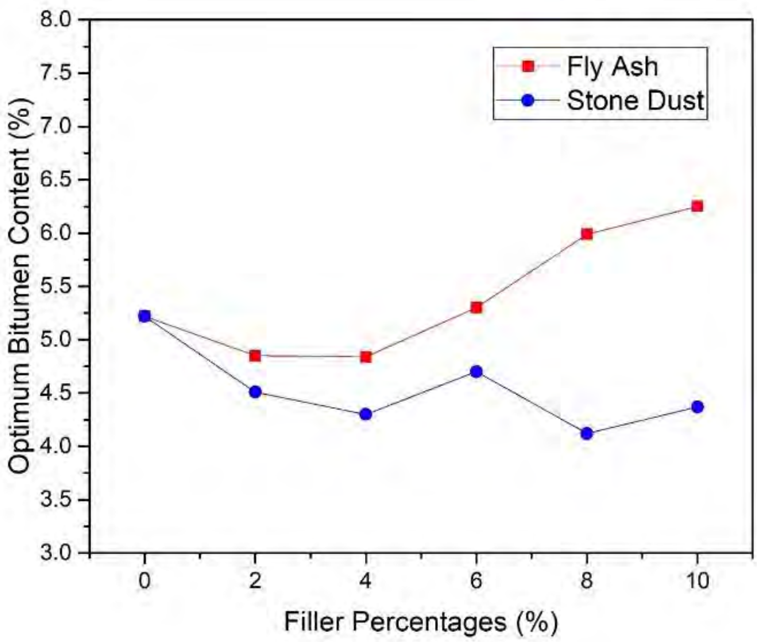


Figure 4.17 Effect of filler type and content on optimum bitumen content

Figure 4.17 shows that the optimum bitumen values follow an increasing trend corresponding to the increase of MWIFA fillers, whereas optimum bitumen values decrease with the increase of stone dust filler except for the optimum bitumen value of 6% stone dust, showing a peak at 4.70%. Celik (2008) found that optimum asphalt contents in mixtures with 5%, 6%, 7%, and 8% fly ash additive were 5.30%, 5.25%, 5.15%, and 5.05%, respectively. When the fly ash additive ratio was increased, the optimum asphalt content decreased. Optimum asphalt contents were determined as 4.70%, 4.75%, 4.80%, and 4.85% in mixtures with 5%, 6%, 7%, and 8% filler additive, respectively, and thus, when the filler ratio was increased, optimum asphalt content also increased. Lakshmayya et al. (2019) found that the optimum binder contents were 4.69%, 4.45%, and 4.73% for 2%, 4%, and 6% additive pond ash, respectively and the optimum binder content values obtained increasing from 2% to 6% PA with a dropped down at 4%. Sargın et al. (2013) found the falling optimum bitumen ratios respecting the increase of Rice husk ash sludge percentages in bituminous mixtures. MWIFA filler mixes exhibit a higher optimum bitumen ratio than SD filler corresponding to each percentage. Usually, OBC is significantly affected by the mineral aggregates, bitumen and mix design. Fly-ash absorbs slightly higher bitumen than stone dust; therefore, it needs more asphalt content (Kar et al. 2014). The optimum bitumen content for each filler percentage is the respective bitumen content at 4% air voids. Table 4.8 indicates the properties of the mixes at their optimum asphalt content for mixes with each filler type and content.

Table 4.8 Marshall Properties of Bituminous mixes at OBC content

Design Criteria	OBC (%)	%Va	%VMA	%VFA	Stability (kN)	Flow (mm)
0% Filler	5.22	4	14.55	72.66	21.16	3.22
2% MWIFA Filler	4.85	4	13.86	71.49	21.06	4.00
4% MWIFA Filler	4.84	4	13.54	70.45	22.99	3.92
6% MWIFA Filler	5.3	4	14.53	72.52	17.98	3.96
8% MWIFA Filler	5.99	4	16.55	75.83	15.88	3.98
10% MWIFA Filler	6.25	4	16.70	75.48	22.69	3.69
2% SD Filler	4.51	4	13.24	69.80	25.06	4.24
4% SD Filler	4.3	4	13.10	69.55	21.18	3.51
6% SD Filler	4.7	4	13.77	71.95	18.37	4.00
8% SD Filler	4.12	4	13.02	69.37	17.79	3.83
10% SD Filler	4.37	4	13.42	70.47	25.27	3.53
Standard Range [a b]	4.90 - 6.5 [a]	3-5 [b]	min 13 [b]	65-78 [b]	min 5.338 [b]	2 - 4 [b]

[a] RHD (2011). Standard specifications for pavement work, Government of the People's Republic of Bangladesh Ministry of Communications Roads and Highways Department, Bangladesh.

[b] Asphalt Institute (2014). MS-2 asphalt mix design methods (7th Edition). Asphalt Institute.

The Marshall Stability values of mixes with MWIFA filler additive at respective optimum bitumen content are within 15 kN to 23 kN. On the other hand, the stability values vary from 17 kN to 25.5 kN for stone dust fillers. Therefore, the SD filler exhibits slightly higher stability than the MWIFA filler. However, all the stability values of both fillers at optimum bitumen content meet the minimum Marshall mix design requirement of 5.34 kN.

In mixes including MWIFA filler, Marshall flow values relative to optimum bitumen levels are obtained within 3.22 mm to 4.00 mm. According to the Marshall mix design criteria of the asphalt institute, the flow values of hot bituminous mixtures used in medium traffic surface and base must be between 2 mm to 4 mm. Marshall flow values relative to optimum bitumen levels in mixes, including SD filler, are found within 3.51 mm to 4.24 mm. The flow values of the two fillers for all percentages except the 2% stone dust filler value are within the Marshall mix design limit.

Voids filled with bitumen values for the optimum bitumen ratios with 0%, 2%, 4%, 6%, 8% and 10% MWIFA filler additive are found within 70.45% to 75.83%. According to Asphalt Institute, the voids filled with bitumen value must be between 65% - 78% in the wearing courses for medium traffic of hot bituminous mixtures. For stone dust filler samples, voids filled with bitumen values for the optimum bitumen ratios with 2%, 4%, 6%, 8%, and 10% are varied from 69.37% to 71.95%. All the VFA values of both fillers at optimum bitumen contents meet the Marshall mix design maximum and minimum VFA requirements.

In mixes including 0%, 2%, 4%, 6%, 8% and 10% MWIFA filler, the percentage of voids in mineral aggregate corresponding to the optimum level of bitumen are found within 13.54% to 16.70%. Design %VMA increases with an increase in MWIFA filler percentage. Jony et al. (2011) and Sargın et al. (2013) found their %VMA values increased with filler percentages in their respective studies. For stone dust filler samples, the percentage of voids in mineral aggregate values for the optimum bitumen ratios with 2%, 4%, 6%, 8% and 10% are within 13.02% to 13.77%. Besides, all the VMA values for both fillers at optimum bitumen contents meet the Marshall mix design minimum requirement of 13%.

4.5 Marshall Immersion Test Result

Mechanical immersion tests are conducted to determine the percentage of stability losses in hot bituminous mixtures under the effect of moisture. The stability loss is defined by the decreased amount of stability in the Marshall sample under specified moisture conditions. The dry Marshall sample loses stability when kept in the water bath for 48 hours at 60◦C. The obtained test results illustrate that the percentage of stability losses varies non-linearly with the variation of filler percentages for both fillers, as shown in Figure 4.18.

According to findings, the percentage of Marshall stability loss is the lowest for the mix containing 8% MWIFA among all mixtures prepared with both fillers. For SD filler mixes, the least stability loss is found at the 10% filler ratio. The corresponding stability losses are 0.7% for MWIFA filler and 12.52% for stone dust filler. Carpenter (1952) and Zimmer (1970) stated that fly ash had an excellent effect on the retained compressive strength for asphalt concrete samples immersed in water. The predominant percentage of CaO in MWIFA filler exhibits water-resistive properties in terms of moisture stability in bituminous mixes (Choudhary et al. 2020). The values of stability losses depict a non-linear relationship with the varying filler ratios for both types of fillers. Akbulut et al. (2012) found a similar trend of stability losses with the increasing granite sludge filler ratios and obtained the minimum stability loss in the 8% filler-containing specimens.

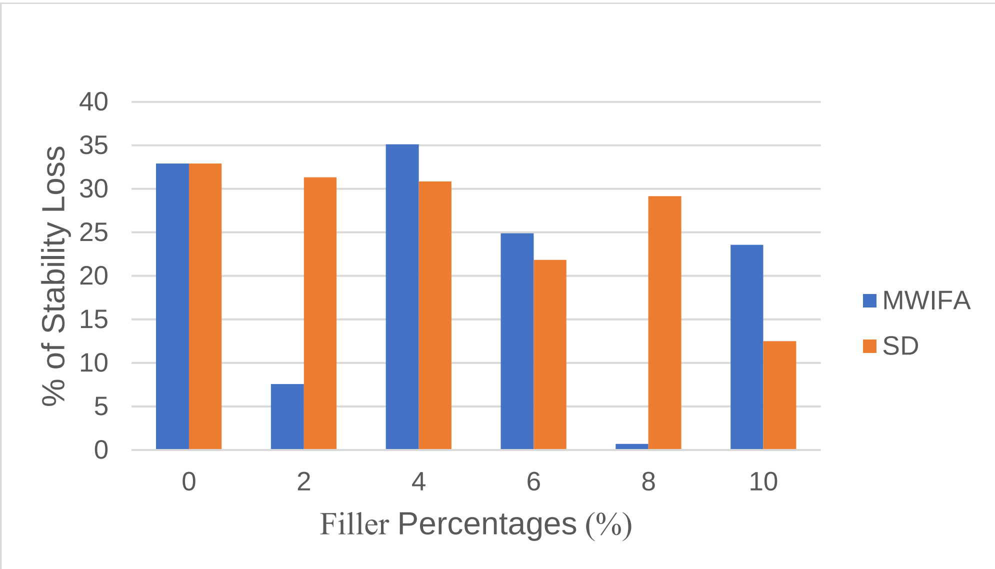


Figure 4.18 Effect of medical waste incineration fly ash and stone dust fillers on stability loss

4.6 Optimum Filler Content

This study aimed to inspect the usability of fly ash from medical waste incineration as mineral filler in asphalt pavement. Marshall hot mix asphalt experiments were done with six different filler proportions to determine the optimum proportion of filler, demonstrating the most excellent comportment in asphalt paving tests. The obtained filler percentages corresponding to maximum stability, lowest Marshall stability lost, maximum density, and the lowest percentage of voids in the hot bituminous mixtures are given in Table 4.9.

The Optimum filler content (OFC) is calculated using equation (3.1) for both fillers. The performance of a hot bituminous mixture in wearing courses can improve using optimum filler percentage (Akbulut et al. 2012). The OFC values found for MWIFA and SD fillers are 5.5% and 9 %, respectively. Lakshmayya et al. (2019) found 4% pond ash as the optimum filler percentage in their study. The portion of 5% fly Ash with 95% crusher dust as optimum filler percentage was determined by Nayak and Mohanty (2020). Sharma et al. (2010) studied the suitability of using fly ashes in bituminous hot mixes. They found that the optimum filler content was 7% and exhibited better performance than conventional fillers. The required optimum filler amount is lower in the asphalt mixes with MWIFA filler than those containing SD filler.

Table 4.9 Design Criteria of Optimum Filler Content

Criteria	Filler Percentage (%)	
Filler Type	MWIFA	SD
Maximum Stability	10	10
Lowest Marshall stability lost	8	10
Maximum density	2	8
Lowest percentage voids in the hot bituminous mixture	2	8
Optimum Filler Content	5.5	9

4.7 Leaching Test Results

Apart from the mechanical properties, the environmental impacts of incorporating waste materials in asphalt and other pavement layers are essential issues that must be considered. These layers are constantly in direct contact with the surface and underground waters, increasing the risk of water pollution by leaching hazardous materials such as heavy metals into underground water resources. A small amount of heavy metals might be needed for health, but the excess will cause acute or chronic toxicity (Halim et al. 2003). The leaching test is used to find out the probable environmental effects as well as the chemical stability of the treated layer (Ilyas et al. 2014).

4.7.1 The Toxicity Characteristic Leaching Procedure Result

TCLP is carried out to identify the waste that is likely to leach the heavy metals and contaminate the groundwater when dumped onto the landfill sites. For this, the heavy metals are extracted from the waste to represent the phenomenon in a landfill. Whenever the concentration of any heavy metal exceeds the international standard limit, it is classified as hazardous (Juel et al. 2016). Leaching of heavy metal is the prime concern for MWIFA, and it should be ensured that after stabilization of MWIFA in the bituminous mix, heavy metal leaching does not exceed the maximum permissible limit even under extreme conditions.

Hence, in this study, the TCLP test was carried out on the raw fly ash sample and the Marshall samples with varying filler percentages from 0% to 10%, each percentage increase by 2% with their respective optimum bitumen ratios.

The concentration results of leachates from raw fly ash and Marshall samples in standard TCLP leaching test and comparison with Land Disposal Restrictions Limits (LDR) for hazardous wastes are given in Table 4.10.

If the metal content increases, the TCLP leaching concentration also increases, but there is no straightforward linear relationship between the metal content and leaching concentration (Xie and Zhu 2013). Eight heavy metals, including As, Pb, Cu, Cr, Cd, Zn, Ni and Hg, are studied. The concentrations of the heavy metals found in raw fly ash and asphalt samples with MWIFA filler are far below the USEPA regulatory limits.

The TCLP test results show minimal risk to the groundwater or stream water line. Most heavy metals leached significantly lower in fly ash as filler than raw fly ash, indicating that toxic metals can be stabilized in the asphalt paving mixture. Modarres et al. (2015) conducted TCLP tests on hot asphalt mixes with coal waste and its ash as mineral filler and found similar results to our study. All the concentrations of heavy metal were below the regulatory limits.

Table 4.10 TCLP test results of raw MWIFA and MWIFA filler (all results in ppm)

Heavy Metals	MWIFA Raw	MWIFA as filler in Marshall Samples					EPA Land Disposal Restriction for Hazardous Waste[d]	
		2%	4%	6%	8%	10%	UTS Limit [b]	TC Limit [c]
As	0.0298	0.0187	0.0254	0.0256	0.0688	0.0251	5	5
Pb	0.169	0.16	0.072	0.08	0	0.125	0.75	5
Cu	0.003	0.059	0.025	0.019	0.01	0.012	-	-
Cr	0.054	0.003	0.067	0.027	0.009	0.07	0.60	5
Cd	0.106	0.089	0.042	0.032	0.085	0.048	0.11	1
Zn	0.011	0	0.001	0.002	0	0.002	4.3	-
Ni	0.003	0.377	0.087	0.076	0.045	0.15	11	-
Hg	Nd [a]	Nd	Nd	Nd	Nd	Nd	0.2	0.2

[a] Nd: Not Detected; [b] Universal Treatment Standards; [c] Toxicity Characteristic Regulatory Level
[d] USEPA (1996). Land Disposal Restrictions for Hazardous Waste, United States Environmental Protection Agency. Available at: https://www.epa.gov/hw/land-disposal-restrictions-hazardous-waste

Table 4.11 Heavy metal reduction by fly ash filler from medical waste incineration

Heavy Metals	% of Heavy Metal Reduction (MWIFA as filler in Marshall Samples)				
	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
As	37.25	14.77	14.09	-	15.77
Pb	5.33	57.4	52.66	100	26.04
Cu	-	-	-	-	-
Cr	94.44	-	50	83.33	-
Cd	16.04	60.38	69.81	19.81	54.72
Zn	100	90.91	81.82	100	81.82
Ni	-	-	-	-	-

Table 4.11 shows the percentages of heavy metal reduction obtained from the stabilized medical waste incineration fly ash as mineral filler in asphalt mixtures. From Table 4.11, it is revealed that the stabilization of MWIFA with asphalt pavement reduces the heavy metal concentration than raw fly ash and thereby reduces the risk of groundwater contamination. As reduces maximum by 37.25% at 2% MWIFA filler sample; maximum reduction percentage for Pb is 57.66% at 4% filler sample, Cr reduces maximum by 94.44% at 2% filler sample, Cd reduces maximum by 69.81 % at 6% filler sample, Zn reduces by 100% at 2% filler sample. All the filler samples increase the amount of copper and nickel without exceeding the EPA Land Disposal limit in Table 4.10.

Hg was not found in this study. Except for Ni and Cu, all heavy metals reduction is satisfactory for stabilizing medical waste incineration fly ash in asphalt pavement mixes. Therefore, it can be concluded that medical waste incineration fly ash can be widely used in paving mixtures without causing any significant environmental hazard even after the end-of-life cycle of these paving constructions.

4.7.2 Dutch Tank Leaching Test Result

The Dutch tank test, NEN 7345, is used to evaluate the leaching performance of solid and stabilized monolith for over a long time (64 days). Two leaching limits (U1 and U2) are used to categorize the environmental impact of the materials in the Dutch Tank test. These (U1 and U2) are two categorizations of material based on the concentration of the existing elements in the material (Malviya and Chaudhary 2006). According to NEN 7345 regulations, if the cumulative heavy metal concentrations of stabilized samples are below U1, the stabilized waste can be used on land and construction material without restriction (Malviya and Chaudhary 2006; Juel et al. 2016).

In our experiment, the cumulative leached concentrations of all the heavy metals were determined and summarized in Table 4.12. All the cumulative concentrations are found far below the regulatory limit U1. Thus, heavy metals (Cd, Ni, Zn, Cu and Pb) were leached in an insignificant amount from monolithic asphalt specimens in acidic water. Therefore, the inclusion of MWIFA in asphalt pavement can be considered environmentally friendly.

Table 4.12 Results of the tank leaching tests in Marshall samples after 8 extractions

Heavy Metals	Cd	Ni	Zn	Cu	Pb
Unit	mg/m^2	mg/m^2	mg/m^2	mg/m^2	mg/m^2
2% MWIFA	0.00018	0.00028	0.00002	0.00005	0.00034
4% MWIFA	0.00034	0.00022	0.00002	0.00005	0.00018
6% MWIFA	0.00022	0.00028	0.00001	0.00008	0.00040
8% MWIFA	0.00035	0.00027	0.00003	0.00015	0.00022
10% MWIFA	0.00022	0.00033	0.00002	0.00006	0.00041
Leaching limits set by the Netherlands Tank Leaching Test (NEN 7345 1993)					
U1	1	50	200	50	100
U2	7	350	1500	350	800

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

Road construction demand in a developing country like Bangladesh is increasing rapidly with the urbanization process. The ongoing rapid growth in traffic demand and traffic loads require continuous development in highway paving materials. There is an urgent need to utilize waste materials in pavement construction to improve highway performance and service life to fulfill sustainability aims. So, medical waste incineration fly ash can be used as a substitute for raw materials to some extent in road construction. The large-scale application of this technology will create economic and commercial demand for MWIFA. So, medical waste management facilities will emphasize the segregation of medical waste from domestic waste and focus on proper management of fly ash instead of landfilling. So, these stabilization technologies release the pressure of raw materials of flexible pavement and reduce the environmental burden of disposal of MWIFA.

5.2 Main Findings

The possible use of MWIFA as filler in a hot bituminous mixture compared to SD filler has been examined through a series of laboratory tests. Fillers in Marshall hot bituminous samples are varied in proportions of 0%, 2%, 4%, 6%, 8%, and 10%. From the analysis of the laboratory test data, the following conclusions and recommendations can be drawn.

1) Leaching test results depict no environmental restrictions on the use of MWIFA in asphalt pavement as filler. The heavy metal concentrations found from the TCLP test results are below the USEPA regulatory limits. The concentration of the targeted heavy metals except Ni and Cu has reduced significantly after stabilizing MWIFA as mineral filler in asphalt mixes detected by the TCLP test. Moreover, all the cumulative concentrations of heavy metals (Cd, Ni, Zn, Cu, and Pb) were found below the Dutch regulatory limit from the Dutch Tank Leaching test (NEN 7345). MWIFA will cause no adverse impact on the environment after stabilization.
2) All the optimum bitumen content levels obtained for each of the different filler percentages are within 4.9% to 6.5%, satisfying the standard limit of

Roads and Highway, Bangladesh. According to this study, optimum bitumen content percentages are obtained as 5.22%, 4.85%, 4.84%, 5.3%, 5.99%, and 6.25% when filler content percentages were set at 0%, 2%, 4%, 6%, 8%, and 10%, respectively. Furthermore, optimum bitumen contents are 4.51%, 4.3%, 4.7%, 4.12%, and 4.37% for the stone dust filler content percentages of 2%, 4%, 6%, 8%, and 10% respectively.

3) The differences between unit weight values of all mixtures with both fillers are not significant. Unit weight values changes in the range of 142.15 lb/cft – 152.95 lb/cft in mixtures with MWIFA. This parameter changed from 148.57 lb/cft – 154.22 lb/cft for mixtures with SD filler. The maximum unit weight decreases with increasing filler content in the mixtures using MWIFA filler. While for mixtures with SD filler, the maximum unit weight keeps increasing with the filler content.
4) MWIFA shows the highest stability of 25.80 kN at 10%. For SD filler, maximum stability decreases up to 6%, then increases up to 10% and shows the highest stability of 27.82 kN at 10%.
5) Stability values of mixes prepared with MWIFA filler are within 10.78 kN to 25.82 kN. For SD filler mixes, stability values are found between 12.9 kN to 27.82 kN. All the Marshall stability values of mixes prepared with MWIFA and SD fillers meet the minimum Marshall mix design criteria of 5.338 kN stability value recommended by the Asphalt Institute. The highest stability for both fillers is found at 10% filler percentage. Maximum stability for SD filler is higher than the mixes containing MWIFA filler for all fillers content except 4%.
6) The design flow values of the two fillers at their respective optimum bitumen content are within the Marshall mix design limit of 2 mm to 4 mm, except the flow value of 2% stone dust filler. There is no significant difference between mixtures with MWIFA and SD fillers for the Marshall flow parameter.
7) All the Voids in mineral aggregate (VMA) values for both fillers at optimum bitumen contents meet the Marshall mix design minimum requirement of 13%. The %VMA values increase with filler content for both fillers. There is no significant difference between all mixtures for this parameter, but the MWIFA filler shows slightly higher values than the SD filler.

8) All the Voids filled with asphalt (VFA) values for both fillers at optimum bitumen contents are within 65% - 78%, thus meeting the Marshall mix design maximum and minimum VFA requirements. The differences between all mixtures for this parameter are insignificant, but MWIFA filler displays slightly higher VFA values than SD filler.
9) The higher % of stability loss values are obtained from mixtures prepared with SD filler compared to MWIFA. MWIFA filler shows more moisture resistance than SD filler.
10) The optimum filler contents for MWIFA and SD fillers are 5.5% and 9%, respectively. The bituminous mixes with 5.5% MWIFA as mineral filler would give better performance in wearing actions, whereas for SD filler, mixed with 9% SD filler will exhibit the same performance. The optimum amount of fly ash filler from medical waste incineration required in asphalt concrete mixes is less compared to stone dust filler.

From the evaluation of the test results, it can be concluded that fly ash from medical waste incineration can be used efficiently as a mineral filler material in asphalt paving mix replacing conventional fillers, especially in areas where MWIFA is abundantly available, and the transportation costs are within the affordable limit. Moreover, the environmental test results exhibit no significant risk of releasing heavy toxic metals, so MWIFA can be considered an eco-friendly stabilized pavement material.

5.3 Recommendations for Future Study

The following may be suggested for future work:

1) More performance-related experiments like fatigue resistance, rutting resistance, ravelling indirect tensile strength, and resilient modulus are recommended to understand the sustainability of MWIFA-incorporated bituminous mixes. Further investigation can be done to study the tensile and flexural strength under repeated load and to test the resistance and durability under many cycles of freezing and thawing.
2) Further studies are required to assess the long-term leaching behaviour (more than one year) of MWIFA-incorporated bituminous mixes.

3) More research can be done to use the fly ash from the medical waste incineration in various aspects such as concrete, brick manufacturing, glass or ceramics manufacturing, and rigid pavement for large-scale utilization.
4) Advanced studies can be to investigate the use of MWIFA as a substitute for clay-sized particles in the embankment, soil improvement, subgrade, subbase, or base materials.
5) Government agencies like RHD, LGED, and City Corporations should undertake pilot studies using MWIFA filler in the bituminous mix. The private sector should also be encouraged and involved.

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APPENDIX

Appendix A

Table A-1 Dimension of Thickness Gauges

Aggregate size fraction		Thickness gauge width of slot of (Average x 0.6) Mm	Minimum mass for subdivision Kg
BS test sieve nominal aperture size			
100% passing (mm)	100% retained (mm)		
63	50	33.9 ± 0.3	50
50	37.5	26.3 ±0.3	35
37.5	28	19.7 ±0.3	15
28	20	14.4 ±0.15	5
20	14	10.2±0.15	2
14	10	7.2±0.10	1
10	6.3	4.9±0.1	0.5

Table A-2 Dimension of Length Gauges

Aggregate size fraction		length gauge Gap between pins (Average x 1.8) Mm	Minimum mass for subdivision Kg
BS test sieve nominal aperture size			
100% passing (mm)	100% retained (mm)		
63	50	-	50
50	37.5	78.0±0.3	35
37.5	28	59.0±0.3	15
28	20	43.2 ±0.3	5
20	14	30.6±0.3	2
14	10	21.6±0.2	1

Table A-3 Gradation of Aggregate

Sieve Size		Weight in gm. of Test Sample for Grade						
Passing (mm)	Retained on (mm)	A	B	C	D	E	F	G
80	63					2500		
63	50					2500		
50	40					5000	5000	
40	25	1250					5000	5000
25	20	1250						5000
20	12.5	1250	2500					
12.5	10	1250	2500					
10	6.3			2500				
6.3	4.75			2500				
4.75	2.36				5000			

Table A-4 Number of Charges as per Grading of Aggregate

Grading	Number of spheres	Weight of charge (gm)
A	12	5000 ± 25
B	11	4584 ± 25
C	8	3330 ± 20
D	6	2500 ± 15
E	12	5000 ± 25
F	12	5000 ± 25
G	12	5000 ± 25

Table A-5 Stability Correlation Ratios

Volume of Specimen	Approximate thickness of the specimen		Correlation Ratio
	mm	in.	
200 to 213	25.4	1	5.56
214 to 225	27.0	11⁄16	5.00
226 to 237	28.6	11⁄8	4.55
238 to 250	30.2	13⁄16	4.17
251 to 264	31.8	1¼	3.85
265 to 276	33.3	15⁄16	3.57
277 to 289	34.9	13⁄8	3.33
290 to 301	36.5	17⁄16	3.03
302 to 316	38.1	11⁄2	2.78
317 to 328	39.7	19⁄16	2.50
329 to 340	41.3	15⁄8	2.27
341 to 353	42.9	111⁄16	2.08
354 to 367	44.4	13⁄4	1.92
368 to 379	46.0	113⁄16	1.79
380 to 392	47.6	17⁄8	1.67
393 to 405	49.2	115⁄16	1.56
406 to 420	50.8	2	1.47
421 to 431	52.4	21⁄16	1.39
432 to 443	54.0	21⁄8	1.32
444 to 456	55.6	23⁄16	1.25
457 to 470	57.2	2¼	1.19
471 to 482	58.7	25⁄16	1.14
483 to 495	60.3	23⁄8	1.09
496 to 508	61.9	27⁄16	1.04
509 to 522	63.5	2¼	1.00
523 to 535	65.1	29⁄16	0.96
536 to 546	66.7	25⁄8	0.93
547 to 559	68.3	211⁄16	0.89
560 to 573	69.8	23⁄4	0.86

574 to 585	71.4	213⁄16	0.83
586 to 598	73.0	27⁄8	0.81
599 to 610	74.6	215⁄16	0.78
611 to 625	76.2	3	0.76

NOTES:

1. The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5-mm (2.5-in.) specimen.
2. Volume-thickness relationship is based on a specimen diameter of 101.6 mm (4 in.).

Appendix B

Table B-1 Marshall Properties Data (MWIFA Filler)

Bulk Specific Gravity with Filler Variations						
Bulk Sp Gravity, Gmm (gm/cc)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	2.323	2.365	2.392	2.354	2.324	1.904
4.5	2.360	2.370	2.407	2.361	2.321	2.278
5	2.383	2.422	2.418	2.386	2.319	2.301
5.5	2.415	2.451	2.424	2.406	2.350	2.295
6	2.417	2.437	2.425	2.400	2.358	2.338
Marshall Stability with Filler Variations						
Marshall Stability (KN)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	18.97	18.21	19.43	14.27	11.51	14.25
4.5	20.56	20.10	21.66	18.54	16.13	16.58
5	22.37	21.47	23.61	20.11	19.70	15.87
5.5	19.58	21.14	23.82	16.52	17.83	25.80
6	18.21	12.66	10.78	15.07	15.85	23.71
VFA with Filler Variations						
Voids Filled with Asphalt (%)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	46.14	52.91	54.97	49.11	48.77	19.40
4.5	57.21	59.92	64.53	56.23	54.00	46.24
5	67.20	76.52	73.19	66.59	59.14	54.09
5.5	79.82	90.22	80.84	76.57	69.28	58.24
6	85.91	92.10	86.78	80.83	75.93	69.81

Air Voids with Filler Variations						
Air Voids (%)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10%Filler
4	8.69	6.86	6.12	7.59	8.21	25.12
4.5	6.52	5.95	4.78	6.63	7.62	9.72
5	4.87	3.15	3.64	4.91	6.96	8.13
5.5	2.86	1.26	2.64	3.38	5.04	7.66
6	2.05	1.09	1.88	2.89	3.98	5.20

Marshall Flow with Filler Variations						
Marshall Flow Value (mm)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10%Filler
4	3.5	3.4	3.1	3.9	4.8	3.9
4.5	4.4	4.2	3.8	3.5	4.3	3.8
5	3.5	4.0	4.0	3.5	3.6	4.0
5.5	2.9	5.1	4.1	4.3	3.7	4.2
6	3.8	5.0	5.5	4.6	4.0	3.8

VMA with Filler Variations						
Voids in Mineral Aggregate (%)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	16.13	14.57	13.58	14.92	16.02	31.17
4.5	15.24	14.84	13.48	15.14	16.56	18.07
5	14.85	13.43	13.57	14.69	17.04	17.70
5.5	14.16	12.86	13.79	14.43	16.41	18.34
6	14.55	13.83	14.23	15.10	16.55	17.24

Table B-2 Marshall Properties Data (SD Filler)

Bulk Specific Gravity with Filler Variations						
Bulk Sp Gravity, Gmm (gm/cc)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	2.323	2.381	2.407	2.420	2.419	2.389
4.5	2.360	2.418	2.430	2.384	2.445	2.436
5	2.383	2.438	2.458	2.464	2.472	2.441
5.5	2.415	2.440	2.452	2.465	2.465	2.455
6	2.417	2.441	2.450	2.445	2.451	2.453
Marshall Stability with Filler Variations						
Marshall Stability (KN)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	18.97	17.84	22.68	20.02	15.85	27.82
4.5	20.56	25.15	20.17	20.75	23.78	24.40
5	22.37	21.69	17.61	14.74	13.17	18.69
5.5	19.58	22.56	17.00	13.68	16.29	16.77
6	18.21	19.10	16.14	12.92	14.80	15.48
VFA with Filler Variations						
Voids Filled with Asphalt (%)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	46.14	55.83	62.53	62.48	66.23	58.64
4.5	57.21	69.53	74.29	62.33	79.04	74.50
5	67.20	80.52	88.05	86.68	92.95	82.04
5.5	79.82	87.45	92.62	93.49	97.22	91.75
6	85.91	93.48	97.64	93.57	98.47	96.95

Air Voids with Filler Variations						
Air Voids (%)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	8.686	6.250	4.997	4.873	4.437	5.928
4.5	6.522	4.037	3.327	5.540	2.651	3.343
5	4.871	2.537	1.483	1.643	0.858	2.405
5.5	2.858	1.679	0.965	0.829	0.358	1.102
6	2.050	0.900	0.321	0.893	0.212	0.423

Marshall Flow with Filler Variations						
Marshall Flow Value (mm)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10% Filler
4	3.5	3.5	4.3	3.4	3.8	3.8
4.5	4.4	4.3	3.0	4.4	3.9	3.4
5	3.5	3.8	4.6	3.4	4.2	5.0
5.5	2.9	4.4	5.3	4.0	5.2	4.8
6	3.8	4.1	4.3	4.4	4.5	5.0

VMA with Filler Variations						
Voids in Mineral Aggregate (%)						
Asphalt Content (Pb) %	0% Filler	2% Filler	4% Filler	6% Filler	8% Filler	10%Filler
4	16.13	14.15	13.34	12.99	13.14	14.33
4.5	15.24	13.25	12.94	14.71	12.65	13.11
5	14.85	13.02	12.41	12.33	12.18	13.39
5.5	14.16	13.38	13.08	12.73	12.86	13.35
6	14.55	13.80	13.62	13.90	13.84	13.87

Table B-3 Marshall stability loss Data

Filler %	Filler type	% of stability loss
0	No filler	32.91
2		7.59
4		35.12
6	MWIFA	24.9
8		0.7
10		23.56
2		31.35
4		30.86
6	SD	21.86
8		29.18
10		12.52

Table B-4 Leaching Sample Data

Filler Type	MWIFA	MWIFA	MWIFA	MWIFA	MWIFA
% Filler	0.02	0.04	0.06	0.08	0.1
OBC	4.85	4.84	5.3	5.99	6.25
BC (gm)	58.84	58.71	64.59	73.49	76.88
Sieve Size	Batch Weight (gm)				
1 inch (25 mm)	0	0	0	0	0
3/4 inch (19 mm)	57.75	57.75	57.75	57.75	57.75
3/8 inch (9.5 mm)	311.85	311.85	311.85	311.85	311.85
No. 4 (4.75 mm)	207.9	207.9	207.9	207.9	207.9
No. 8 (2.36 mm)	173.25	161.7	161.7	150.15	138.6
No. 50 (0.3 mm)	288.75	277.2	265.65	254.1	242.55
N0. 200 (0.075 mm)	92.4	92.4	80.85	80.85	80.85
Mineral Filler	23.1	46.2	69.3	92.4	115.5
Total	1155	1155	1155	1155	1155