

## PERFORMANCE EVALUATION OF HOT MIX ASPHALT (HMA) BY USING NANO SILICA AND FLY ASH

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**Abstract**

Roads are an essential requirement for human civilization, and a majority of roads worldwide are constructed using flexible pavement. However, these roads are prone to damage, such as cracking, potholes, and rutting, primarily due to factors like heavy traffic, high loads, and significant temperature fluctuations. Furthermore, in our country, there is a substantial production of fly ash, which directly contributes to environmental pollution. Recycling waste materials while building pavement gives significant cost savings over buying new materials and also reducing the amount of waste that needs to be disposed of.

We carried out research to determine the effects of utilizing Nano silica & Fly ash as mineral fillers on both the Marshall Properties & flow properties of Hot Mix Asphalt (HMA). We added nano silica at a percentage of the total binder content and fly ash at a percentage of the filler content. Different combinations with binder levels ranging from 3.5% to 5% were examined, including 4% fly ash with 2% nano silica, 8% fly ash & 4% nano silica, & 12% fly ash & 6% nano silica.

The research findings indicated that the most favorable outcome was achieved with a combination of 8% fly ash and 4% nano silica at a binder content of 4.5%. Maximum stability, comparatively good flow values, a low amount of air voids, and the highest amounts of VMA (voids in mineral aggregate) & VFA (voids filled with asphalt) were all displayed by this particular combination. These findings demonstrate the value of adding fly ash & nano silica to the asphalt mixture and their potential to improve the functionality and longevity of flexible pavement.

By utilizing waste materials like fly ash, we can contribute to sustainable construction practices while mitigating environmental pollution. The outcomes of this study provide valuable insights for the development of cost-effective and eco-friendly pavement construction techniques.

## INTRODUCTION

### 1.1 Background

Road pavement performance and durability have been greatly improved recently by the transportation infrastructure sector. Hot Mix Asphalt (HMA) is a critical component of road construction, ensuring pavements' structural integrity and longevity. However, the exposure of HMA to environmental factors such as heavy traffic loads, temperature fluctuations, and moisture poses challenges to its performance and sustainability. These difficulties show up in problems including rutting, fatigue cracking, heat cracking, & moisture damage, which have an impact on HMA's overall performance. In order to overcome these difficulties, academics and professionals have been investigating methods including incorporating additives such nano silica & fly ash to improve the qualities of HMA. In order to build more durable and robust road pavements, this research intends to assess the effects of nano silica & fly ash on HMA.

### 1.2 Filler

It is the most important component of hot mix asphalt (HMA) which fills the space between the bitumen and aggregates in flexible pavement. According to (AASHTO) filler is that portion of hot mix asphalt which passes on sieve No. 200 and retains on the pan. Filler is the major element in

the asphalt mix concrete mixture. It helps in the compaction of asphalt concrete. It has a great impact on the properties of the HMA mixture. Many Research has been carried upon various fillers in HMA for properties enhancement. The effect of filler on bituminous concrete depends upon the intrinsic properties of fillers, their chemical combination, absorbing capacity, specific gravity etc. All these properties lead different types of fillers to behave differently in bituminous concrete. Many types of mineral filler are used as a filler e.g.(rock dust, stone dust, hydraulic cement, marble dust etc.[1].

But here we are interested in using waste Fly ash as filler and nano silica as a percentage of binder in HMA to enhance the properties of asphalt concrete.

### 1.3 Nano silica

In the modern era, nano silica is widely employed in the concrete, pharmaceutical, engineering, and medical fields. Nano silica significantly improves concrete's performance and provides a number of benefits at a reasonable cost. This mineral has a sizable surface area, a high capacity for absorption, outstanding stability, equal distribution, and a high purity. Nano silica comes in particle sizes between 10nm and 100nm. It greatly affects the binder's characteristics because of its nano size[2].



Figure 1-1: Nano silica

#### 1.4 Fly Ash

In electrical power generation plants, combustion of pulverized coal produces a byproduct called fly ash. The carbon and volatile substances are burnt off when the pulverized coal ignites inside the

combustion chamber. Clay, shale, feldspars, and other mineral impurities can fuse in suspension and be expelled from the combustion chamber into the exhaust gases. The fused components form into spherical glassy particles known as fly ash as the exhaust fumes cool.[3].



Figure 1-2: Fly Ash

#### 1.5 Problem statement

Flexible pavement is the type of pavement in which we use binder and aggregate. A mix of coarse aggregate, fine aggregate, mineral filler, and a negligibly small amount of asphalt binder makes up hot mix asphalt (HMA). Due to heavy traffic loads and temperature variation, these types of failure occur such as cracking, pot holes and rutting etc. These kinds of routes may result in mishaps. These issues are all connected to the hot-mix asphalt's marshaling characteristics. It has been noted that the durability of the wearing course is influenced by the strength of the filler and aggregate. The influence on asphalt's mechanical qualities has risen with the addition of a tiny amount of binder (approximately 5% by mass). Previous studies have shown that several additives such as marble dust, fibers, rubber, lime, mixtures of fibers and polymers etc., are frequently used to modify the asphalt binder which may improve the qualities of asphalt. Recently, the HMA was modified using cutting-edge methods that included mineral fiber and waste tire rubber. They were successful in increasing the asphalt mixtures' resistance to rutting and cracking respectively. Nano silica is being utilized to

increase the permeability, abrasion resistance, binding strength, and compressive strength of cement concrete. Thermal power facilities generate vast quantities of fly ash, a byproduct that is utilized as filler.

#### 1.6 General objective

Performance evaluation of hot mix asphalt using fly ash as a filler and nano silica as a percentage of binder filler.

#### 1.7 Research Objective

To evaluate the benefits in terms of improved marshal stability and flow in Hot Mix Asphalt. To evaluate the performance of modified Hot Mix Asphalt by adding nano silica as a percentage of binder and fly ash as filler.

#### 1.8 Organization of Thesis

There are five chapters in this thesis. Each chapter's specifics are listed below.

#### 1.9 Chapter 1

In this chapter, we define the filler nano silica and fly ash and their possible use in hot mix asphalt pavement, problem statement and research objective.

### 1.10 Chapter 2

Includes a literature review on the needs of transportation, design methods of flexible pavements, types of pavements, Marshall mix design and previous research related to the use of these waste materials as filler. Finally, it includes research on different test methods used for determining the Optimum Bitumen Content (OBC).

### 1.11 Chapter 3

Explains the methodology adopted in this research which includes the collection and laboratory characterization of materials, the Marshall mix design and performance testing and their analysis.

### 1.12 Chapter 4

Test and analysis on bitumen using nano silica and fly ash.

### 1.13 Chapter 5

Summarizes the conclusion of Future recommendations are also discussed and references.

## LITERATURE REVIEW

### 1.14 Introduction:

This chapter includes a brief discussion of the theory relating to the need of transportation, varieties of pavement, and various pavement design techniques. Some overview on nano silica and fly ash and its effect on pavement and discuss different research papers on it.

### 1.15 Transportation

Transportation plays a crucial role in the economic development of a country, enabling efficient communication and the seamless transfer of goods. A well-developed transportation system contributes to the prosperity of a nation. Pakistan, once plagued by poor transportation infrastructure has made significant progress in this regard. Notably, the construction and expansion of motorways have been pivotal in transforming the transportation landscape. As of February 4, 2017, Pakistan's motorway network spanned 1,010 kilometres with an additional 3,690 kilometres under construction set to be completed by 2019. The establishment of metro services in

cities such as Islamabad, Lahore, Peshawar, and Multan have further revolutionized transportation within the country. The Orange Line train service in Lahore serves as a notable example of this transformation. Furthermore, the China-Pakistan Economic Corridor (CPEC), a collaboration between Pakistan and China, encompasses a range of infrastructure projects valued at \$54 billion. This initiative includes the construction of a 1,100-kilometer motorway connecting Karachi and Lahore. Notably, the completion of the Karakoram Highway, linking the China border at Khunjerab with Rawalpindi, is imminent and promises improved connectivity.

### 1.16 Pavement:

The main purpose of a highway pavement is to convey the applied load of vehicles to the subgrade. A highway pavement includes a structure made up of multiple layers of processed materials overlaid above the soil's natural subgrade. The construction of the pavement should be able to offer reduced skid resistance and good riding characteristics. The primary goal is to ensure that the strains caused by wheel load are suitably decreased so as not to surpass the subgrade's bearing capability[4].

#### 1.16.1 Types of Pavements

There are two types of pavements.

- Flexible Pavement.
- Rigid Pavement.

##### 1.16.1.1 Flexible Pavements

A flexible pavement is a structure which transfers weight to the subgrade while maintaining close touch with it, and its stability depends on the aggregate combination, particle friction, and cohesion. The material layers are typically placed so that the top layer of the road has a higher load-bearing capacity than the bottom layer of the road, which has a lower load-bearing capacity and is less expansive. Flexible pavement consists of several layers such as subgrade, sub-base, base and wearing course. The subgrade is a natural soil and the subbase and base are in between the subgrade and wearing course. The material used in the sub-base

and base layer is gravel and fine aggregate but the top of the layer is wearing course which is a mixture of asphalt cement and aggregate. For the top layer to withstand the most compressive stress, it must be of the highest quality.

Low flexural strength and a bituminous surface characterize flexible pavement. Its design depends on how component layer loads are distributed. The aggregate interlock & friction between them

determine how stable flexible pavement is. In flexible pavements, the subgrade deformed and this caused the upper layers to deform as well. Flexible pavement has a low initial cost but significant ongoing costs. There are numerous ways that flexible pavement might fail, including wear and tear, bleeding, rutting, patching, and potholes, all of which happen above the top layer[5].

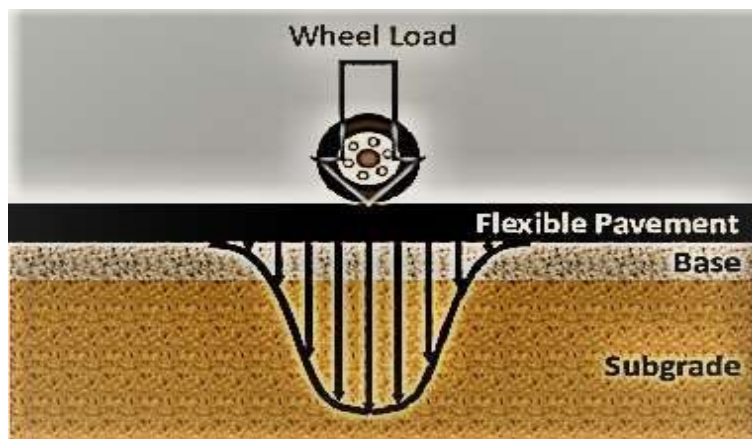


Figure 0-1: Flexible Pavement[6]

#### 1.16.1.2 Rigid pavements:

Concrete reinforcing slabs and cement concrete form rigid pavement. Because of the high modulus of elasticity of their plan course, rigid pavement's structure bends relatively little under loading. A PCC surface course is commonly used to construct stiff pavement structures, and it is placed on above either the subgrade or a basic base course. A 'concrete paver' is used to lay rigid pavements in a single layer. Non-continuous pavements have joints to accommodate thermal movement. 'Filler' and surface sealant are used in the junction. has a strong flexural capacity.

The design of rigid pavement relies on the bending strength of concrete or the slab's action, and the pavement slab itself provides the structural strength through the action of its beams.

Subgrade deformation is not carried over to higher levels. Heavy trucks are often preferred on rigid pavement due to its greater initial cost, low maintenance costs, and longer lifespan (30+ years). Rigid pavement surfaces can be installed directly on the subgrade. Given that concrete has a very limited capacity for contraction and expansion, thermal stresses can cause more damage. Expansion joints are necessary because of the significant strains that temperature fluctuations place on inflexible pavements. The subgrade's strength has less of an impact on the road's strength. The road cannot be utilized until it has been allowed to cure for 14 days without needing to be compacted. Rigid pavement has great skid resistance and settlements are irreversible because of deformations brought on by heavy wheel loads[5].

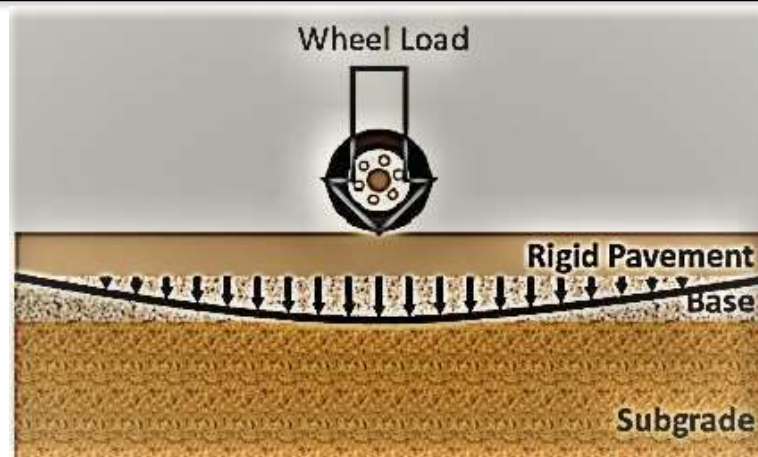


Figure 0-2: Rigid Pavement[6]

### 1.17 Use of Fly Ash in previous research:

#### 1.17.1 Examining the Impacts of Using Fly Ash as a Hot Mix Asphalt Filler in Place of Common Filler

This study investigates the effects of substituting fly ash for traditional filler in the hot-mix asphalt. The investigation focuses on varying percentages of bitumen content in the asphalt mixture, ranging from 3.5% to 6.5% in increments of 0.5%. Additionally, 2% hydrated lime is included in the control mix, while modified mixes feature fly ash fillers at percentages of 2%, 4%, 6%, and 8%. The experimental results show that, in comparison to the traditional mix and standard standards, the asphalt mixture containing 4% of fly ash as a substitute filler exhibits superior stability values & a lower optimal bitumen content (OBC). As a result, this study reveals the positive results obtained when using the fly ash as a substitute filler in a hot-mix asphalt[7].

#### 1.17.2 Rice Husk & Fly Ash as Alternate Fillers in Hot Mix Asphalt: An Experimental Study for Environmental Sustainability

In order to improve environmental sustainability by the use of waste from agriculture and industry in construction practices, this research study provides an experimental evaluation of the use of rice husk ash (RHA) & fly ash (FA) as alternate fillers in hot mix asphalt (HMA). The study looks at what happens when RHA and FA are employed in place of the typically utilized hydrated lime (HL)

filler in HMA. The findings have been compared with a control mix after design mixes made using the Marshall method were made with different ratios of fly ash & rice husk that ranged from 2% to 8%. The results show that using fly ash & rice husk as substitute fillers improved the performance for the hot mix asphalt. A decrease of 7.5% in the optimum amount of bitumen relative to the control mix if a 4% alternate filler ratio was used also shows that including these alternative fillers increased economic efficiency[8].

#### 1.17.3 Examining how the mechanical properties of hot-mixed asphalt are affected by the use of fly ash for filler replacement

This study aims to investigate the effects of substituting fly ash for filler on the mechanical characteristics of hot mix asphalt (HMA). When utilized as a filler in HMA, fly ash, a by-product of coal-fired power generation, offers substantial benefits from an environmental and financial standpoint. Soma fly ash, cayirhan fly ash, & kangal fly ash are the three varieties of fly ash that are the subject of the study. The results show a distinct drop in flow value and an increase in Marshall stability, especially when soma fly ash, among the three varieties of fly ash, is used as a filler. The actions of concrete asphalt pavement with applied loads is significantly altered by these changes in mechanical characteristics, principally through bitumen extension. Additionally, compared to specimens employing calcareous

filler, the fatigue-related life of fly ash specimens, particularly soma fly ash, was significantly longer. This study clearly shows that fly ash can be employed in dense-graded wearing courses as a filler alternative[9].

#### **1.17.4 Examining Fly Ash's Impact as a Filler Alternative in Hot Mix Asphalt Concrete Mixtures**

The use of fly ash as an alternative filler substitute for hot mix asphalt (HMA) mixtures for concrete is the main topic of this research article. The Soma Thermal Power Plant provided the fly ash for the study. As fillers, fly ash was added to the HMA mixtures in various amounts, including 5%, 6%, 7%, & 8%. Comparative samples that contained filler of the same percentage of the fly ash mixture were created without any additions. The samples were subjected to Marshall tests to establish the ideal asphalt content. The outcomes show that substituting fly ash for filler resulted in greater stability values. In particular, the mixture containing 5% fly ash as a filler had the best stability rating[10].

#### **1.17.5 Effect of Filler Material on Asphalt Concrete's Volumetric & Mechanical Performance**

This study investigates how filler material affects the mechanical and volumetric properties of asphalt concrete. Alternative fillers are used to create hot mix asphalt with 60/70 grade bitumen. A universal testing machine & a-controlled temperature chamber is used to conduct various tests, such as indirect tensile, resilient modulus, & dynamic creep, at controlled temperatures (25°C and 55°C). By preparing samples in wet settings, moisture susceptibility is assessed. Cement and fly ash fillers greatly improve the strength, stiffness, & stripping resistance of the asphalt mixture, according to the results. Additionally, using fly ash and cement together increases rutting resistance in wet and hot weather. Overall, the results show that adding filler elements enhances asphalt concrete's strength, stiffness, and susceptibility to moisture in comparison to simple mix designs[11].

#### **1.17.6 Fly ash's effect on the mechanical characteristics of asphalt mixtures**

This study examines how fly ash affects the mechanical characteristics of asphalt mixtures. Examining the robust modulus, creep, permanent deformation, & fatigue properties at three distinct temperature ranges is the main goal of the study. According to the findings, using the fly ash as a mineral filler raises the asphalt mixture's robust modulus. However, the performance of the hot mix asphalt with regard to of rutting depth is unaffected by the addition of fly ash. It is important to remember that adding fly ash does enhance the likelihood of pavement surface cracking[12].

#### **1.17.7 Fly ash as a Mineral Filler Alternative: A Study on the Use of Waste & Alternate Materials in Hot Mix Asphalt**

This study investigates the utilization of waste & alternative components in the production of hot-mix asphalt, concentrating on the addition of fly ash. In order to replace 25%, 50%, 75%, & 100% of the mineral filler, experimental studies on mixtures of asphalt concrete using fly ash from three distinct sources were carried out. Additionally, a control mix made entirely of mineral filler was created. Marshall & flow tests were performed on the samples to evaluate their effectiveness. The findings show that adding fly ash can result in a volumetric composition that is suitable. The sort of fly ash utilized affects the bulk density & air spaces for both the mineral & asphalt compositions. Additionally, combinations containing fly ash are less sensitive to water than control mixtures, with the amount and kind of fly ash used being a determining factor[13].

#### **1.17.8 Use of Rice Husk Ash & Date Seed Ash as Cheaper and Environmentally Friendly Alternate Filler materials with Hot Mix Asphalt**

This study examines the use of substitute fillers in hot-mix asphalt in order to meet the growing concerns about raw material usage and environmental issues. The investigation examines two biomass ashes as potential replacements for traditional fillers, ash from rice husks and date

seed ash. To replace the usual filler in asphalt concrete, different ratios of rice husk ash & date seeds ash (0%, 25%, 50%, 75%, & 100%) were used. Several experiments, include Marshall stability, indirect tensile stiffness modulus, four-point bend fatigue, and wheel tracking tests, were carried out to evaluate the mechanical characteristics of the asphalt concrete. According to the findings, adding rice husk and date seed ash to hot mix asphalt improves stiffness modulus and stability when compared with the control mix. Additionally, the use of rice husk ash & date seed ash boosts the mixture's thermal sensitivity and strengthens the bonds that attach the asphalt & aggregate, reducing rutting depth and extending the hot mix asphalt mixture's fatigue life[14].

### 1.18 Use of Nano silica in previous research paper

#### 1.18.1 Enhancing Hot Mix Asphalt Mixture Characteristics Using Nano silica

Incorporating nano silica will help the qualities of hot mix asphalt mixture, which is the main topic of this research work. The percentage of nano silica in the modified hot mix asphalt is varied throughout the study to be 3%, 5%, 7%, 9%, & 11% by weight of bitumen. Wheel tracking, indirect tensile strength, & direct compression tests are used to assess the mechanical qualities of the modified asphalt mixture. The outcomes show that the bitumen/nano silica weight ratio of 7% is ideal for an asphalt mixture. With this mixture, Marshall stability increases noticeably by up to 25% while flow decreases by up to 19%. Additionally, nano silica can cut rutting depth by as much as 40%. Overall, the properties in the hot mix asphalt mixture are improved by the inclusion of nano silica[15].

#### 1.18.2 Evaluating the Performance of Nano silica as a Binder Modifier in Hot Mix Asphalt Concrete

This study intends to evaluate the properties of asphalt hot-mix concrete that has been altered with different amounts of nano silica (2%, 4%, 6%, & 8% by weight of bitumen). Through the use of Marshall stability, dynamic creep, &

indirect tensile tests, the performance of the modified asphalt is assessed. The findings show that using nano silica as a binder modifier enhances the hot mix asphalt's marshall stability, indirect tensile strength, and resilient modulus[1].

#### 1.18.3 Enhancing Performance of Hot Mix Asphalt through Nano silica Modification

The alteration of hot mix asphalt using nano silica at a percentage of bitumen by weight is the main topic of this study article. The study looks at how nano silica affects the asphalt mixture's resistance to rutting and fatigue. Additionally, the modified hot mix asphalt's susceptibility to moisture is assessed using the Lottman test method. Scanning electron microscopy is also used to characterize the nano particles. According to the findings, bitumen containing 0.3% by weight of nano silica performs at its best, showing a 26.25% greater resistance to moisture than the reference sample[16].

#### 1.18.4 Enhancing Performance of Hot Mix Asphalt and Bitumen through Nano Material Modification

This study examines how adding nanomaterials to hot mix asphalt & bitumen affects their performance. Multi-walled Carbon Nano Tubes (MWCNTs) & Carbon Tubes doped with 50% weight of Silicon Dioxide Nano Powder are specifically used to modify the asphalt mix. Bitumen is blended with the nano materials at various weight ratios of 1%, 3%, and 5%. A modified Lottman test is used to determine moisture susceptibility, and the rutting and fatigue performance of the modified asphalt mixture are assessed. The outcomes show that adding nanomaterials as a binder to hot mix asphalt enhances its functionality. The investigation also showed that the majority of the agglomeration of nanomaterials in the combination is lower than 4 $\mu$ m[17].

## RESEARCH METHODOLOGY

### 1.19 Introduction

The experimental methodology used to assess the performance of hot-mixed asphalt (HMA) mixtures including fly ash and nano silica is

presented in this chapter. The chapter outlines the research approach, materials and mixtures, testing procedures, and data analysis methods utilized in the study. To ensure accurate and trustworthy results and to assess how fly ash and nano silica affect the performance of HMA, a thorough and methodical technique is essential.

### 1.20 Research Approach

The methodology used for this study entailed running laboratory tests to gauge how well HMA mixtures with various amounts of nano silica & fly ash performed. The study focused on specific properties such as rutting resistance, fatigue life, moisture damage resistance, and cracking resistance. The experiments were conducted following standard test methods and procedures to ensure consistency and comparability of results.

### 1.21 Materials and Mixtures

The materials used in the study included aggregates, asphalt binders, nano silica, and fly ash. The aggregates were carefully selected based on their gradation and quality to meet the specifications for HMA mixtures. The asphalt binder used was a commonly used binder with suitable properties for the intended application. Nano silica and fly ash were sourced from reputable suppliers and met the required specifications.

Different HMA mixtures were prepared by incorporating varying percentages of nano silica and fly ash. The percentages were selected based on previous research and preliminary investigations to ensure an optimal range for performance evaluation. Control mixtures without any additives were also prepared for comparison purposes.

### 1.22 Materials used to research how hot mix asphalt performs

#### 1.22.1 Aggregate

The following characteristics of the mineral aggregates utilized as both coarse and fine aggregates in the study were discovered through a local search.

#### 1.22.2 Aggregate quality

The quality & physical characteristics of the aggregate, which makes up the majority of hot mix asphalt have a significant impact on how well asphalt concrete performs. Shape, hardness, and durability were typically used to characterize the attributes needed in aggregates. Rock that has been crushed and untethered comes from a permitted quarry. The aggregate utilized to create the specimen thus has the following properties. Clean and devoid of organic matter and clay. To provide strong mechanical interlock, an object should be angular and not overly flaky. Strong enough to withstand crushing while mixing, laying, and in use. Resistance to polishing and abrasion when in contact with traffic.

#### 1.22.3 Tests on Aggregate

Aggregate testing is a crucial component of the Job Mix Formula since the strength of asphalt concrete is directly related to the aggregate's strength and durability. The sieve analysis of aggregate gradation, the Los Angeles (LA) abrasion test, the aggregate Impact value test, as well as specific gravity of both coarse and fine aggregates, were tests conducted for aggregate.

##### 1.22.3.1 Sieve analysis & gradation

In the lab, aggregates from nearby searches were sieved. Each sieve's retained material was stacked up in its own bag. The NHA Class A Grading System and the NLC Rehabilitation Project Grading System were both adopted.

Table 0-1: Sieve analysis of coarse aggregate:

Sieve analysis & gradation Sieve Size (mm)	Sieve Size (inches)	Lab Trial	NHA Class A specification
25	1	100	100
19	¾	95	90-100
12.5	½	67	~

9.5	3/8	60	56-70
4.75	#4	44	35-50
2.36	#8	30	23-35
0.30	#50	9	5-12
0.075	#200	5.6	03-08



Figure 0-1: Sieve Analysis

### 1.22.3.2 AIV DETERMINATION (BS 812-112): AGGREGATE IMPACT VALUE

This test is carried out to determine the aggregate's relative strength vs the impact loading of various traffic loads. The impact load and pounding action of traffic increases the likelihood of aggregates disintegrating into smaller fragments. Aggregates must therefore be sufficiently hard and robust to withstand fractures brought on by the impact-loading action of traffic. The BS: 812 and IS 383 requirements are used to execute this test.

The aggregate chosen for this test weighed about 350 grams and passed through a 14-mm screen while being retained on a 10-mm sieve. Three layers of aggregate were added to the Impact testing machine cup, and with the aid of a tamping rod, each layer was pounded 25 times. Following compaction, a typical 14 kg hammer was used to blow the aggregates while falling from a 38 cm height. They were removed from the cup & subjected to additional sieving using a 2.36mm sieve after receiving the prescribed number of blows. The data are given as a % of particles passing a 2.36mm sieve

Table 0-2: Impact value of aggregate

Sr No.	Weight of aggregate passing 14mm and retained on 10mm sieve(W1) in g	Weight of fines passing 2.36mm sieve(W2) in g	Impact of aggregate $\frac{W2}{W1} \times 100(\%)$
1	350	92	26.28%
2	350	86	24.57%
3	350	79	22.57%
Average value		24.47%	

#### 1.22.3.2.1 Specification of Impact Value of Aggregate

Impact Value < 10 % exceptionally strong

Impact Value 10 % to 20 % Strong

Impact Value 20 % to 30 % Satisfactory for road construction

#### 1.22.3.2.2 Comments

The impact value of an aggregate is 24.47% which is in the range of 20-30%, so the aggregate is strong and can be used for wearing course.

#### 1.22.3.3 Los Angeles Abrasion Test

Designation:(ASTM C 535 & AASHTO T-96)

Heavy traffic loads require that the aggregates in asphalt hot-mix mixtures be able to withstand crushing, deterioration, and disintegration. The durability & toughness of aggregates are evaluated for this purpose using a LA abrasion test. According to AASHTO T 96-92 specifications, this test is conducted. The three approaches that were evaluated on aggregates are listed in Table 3.3 below. The finished product was sieved from sieve #12 after aggregate underwent standard method abrasion with a required number of 27 balls. The weight loss following abrasion was calculated, which was found to be below forty percent, in accordance with the standards.

Table 0-3: Los Angeles abrasion

Sr No.	The original weight of the aggregate sample in (g)(W <sub>1</sub> )	Weight passing #12 sieve in (g)W <sub>2</sub>	$\frac{W2}{W1} \times 100(\%)$
1	5000	808	16.16%
2	5000	814	16.28%
Average Value		16.22%	

#### 1.22.3.3.1 Specification

For wearing surface limit= (0 to 30%)

#### 1.22.3.3.2 Comments

Our result 16.22% which comes in the range of (0-30%), so the aggregate is good and used for wearing the surface of the road.

#### 1.22.3.4 Elongation And Flakiness Index of Aggregate

Designation:(ASTM D 4791-99)

The elongation index is a measure of the percentage of particles in the aggregate that are elongated or have a length greater than a specified ratio to the average particle size. It helps assess the shape characteristics of the aggregate particles. The flakiness index, on the other hand, measures the percentage of particles with a

thickness less than a specified ratio to their average size. It evaluates the flatness or thinness of the aggregate particles.

**Table 0-4: Elongation and Flakiness Index of Aggregate**

Size of sieves (g)	Weight Weight of elongated particles(g)	Weight of flaky particle(g)	
Retained (in)			
1	W1=0	E1=0	F1=8
3/4	W2=132	E2=0	F2=109
1/2	W3=754	E3=99	F3=25
3/8	W4=92	E4=5	F4=25
4	W5=22	E5=0	F5=3
	$\Sigma=1000g$	$\Sigma=104g$	$\Sigma=145g$

Flakiness index=  $\Sigma F / (\text{total weight}) \times 100(\%) = 145/1000 \times 100(\%) = 14.5\%$

Elongation index=  $\Sigma E / (\text{total weight}) \times 100(\%) = 104/1000 \times 100(\%) = 10.4\%$

#### 1.22.3.4.1 Specification

Flakiness index = <15%

Elongation index = <15%

#### 1.22.3.4.2 Comments

The flakiness and elongation index values are 14.5% and 10.4% respectively. So, this aggregate is used for wearing the surface of the road.

#### 1.22.3.5 Fine aggregates' specific gravity and water absorption

The SG & WA test for fine aggregate was carried out in accordance with AASHTO T 84-93's guidelines. Like coarse aggregates, fine aggregates were porous and can absorb water. Passing sieve #4 was immersed in a tub of water for roughly 15 to 19 hours in order to determine the SG & WA fines aggregates. The sample had been spread out over a steel tray after the allotted amount of time. With the use of an air dryer, it was dried until the surface was fully dry. Then, a cone was set down on a flat area and overflowed with particles. With the use of a tamper, it had been tamped 25 times. The cone was then taken away, and the particles were dried once more to the point where they still had some of their mold-like characteristics. 500g of the SSD fines were taken after reaching SSD in its entirety. A pycnometer was then filled with water up to the mark required, weighed, and SSD fines were added while maintaining the water level at the mark. The filled assembly as a whole was

then weighed. Then, these particles were dried in a 110°C oven. The following equations were used to calculate the bulk values of SG and WA.

The SG & WA test for fine aggregates were carried out in accordance with AASHTO T 84-93's guidelines.

- Bulk Specific Gravity =  $A / (B + SSD - C) * 100$
- Absorption =  $B - A / A * 100$
- BSG = 2.55
- Absorption = 1.6%

#### 1.23 Bitumen

Asphalts, also known as bituminous materials are widely utilized in the construction of roads, principally due to their outstanding waterproofing and binding capabilities and affordable price. Bitumen, a solid with a dark color or a black hue, is a component of bituminous materials. It is also a viscous cementation substance with adhesive qualities that is mostly made of higher-molecular-weight hydrocarbons extracted from petroleum or natural asphalt. Bitumen is also soluble in carbon disulfide. Tars are more temperature sensitive than bitumen and are byproducts of the damaging distillation of organic materials like coal, wood, or petroleum. In contrast to tar, bitumen will dissolve in petroleum oils.

##### 1.23.1 Bitumen Tests

The implementation of certain test techniques that are indicative of the qualities that define

suitable performance levels is the result of experience utilizing bitumen in engineering projects. Some of the tests, which use empirical methodology, have changed as the sector has grown. In order for them to be precise measurements regarding the bitumen's properties, they have to be carried out in exact accordance with the suggested techniques.

### 1.23.2 Penetration Test (ASTM: D5-86)

It is the bituminous material's consistency expressed as the distance, in tenths of a millimeter, that a standard needle can vertically penetrate a sample of the material under loading, duration, and temperature conditions that are known. Standard testing parameters include a 25 °C temperature, a 5 second testing period, and a 100-gram load.



Figure 0-2: Penetration test

### 1.23.3 Softening point Of Bitumen (ASTM: D36-81)

It refers to the temperature when the sample gets soft enough to permit a ball fall a distance of 1 inch (25.4 mm) while being encased in the sample material. A steel ball with a diameter of 3/8 inches and a weight of 3.5+0.85 grams is used as the testing condition for the softening point. Brass is used to make the ring. The base plate must be made of an impermeable material, thick enough to prevent deformation, large enough to contain two or more rings, and colored. The thermometer must be suspended to ensure the bottom of the bulb is level with respect to the bottom of the rig, with a minimum distance of (12.7 mm) and a maximum distance of (99.1 mm) between the lower surface of the bottom plate & the bottom of the bath. 50C per minute should be the heating rate.

### 1.23.4 Flash & Fire point test (ASTM: D36-81)

The maximum temperature that asphalt can be safely heated in the presence of a burning flame is determined by the Flash & Fire point. For the purpose of determining the flash & fire point, the samples were put into open cups and heated. Flash points are where a tiny flame ignites at the surface, and fire points are where a fire ignites within a sample. Typically, the fire is started by vapours in the bitumen sample.

### 1.23.5 Ductility Of Bitumen Test

When the ends for briquette spacemen made of the material are dragged apart at a specific speed and temperature, the distance that elongates before braking is used to determine the quality of bituminous material. The instrument pulls the sample out at a pace of 5 cm/sec, and the testing temperature, which is typically 25 oC or 77 oF, must be maintained. Water must have a specific gravity of 1. There must be consistency in the pull exerted from the two holders.



Figure 0-3: ductility test of bitumen

**1.23.6 Bituminous Binder**

Since it is popular and appropriate for hot temperatures, a bituminous binder of grade 60/70

penetration was employed to prepare the combinations.

Table 0-5: test on bitumen

No.	Test Type	Test Method	Test Results
1.	Flash Point	AASHTO T 48	300 °C
2.	Ductility at 25 °C	AASHTO T 51	110 cm
4.	Specific Gravity at 25 °C	AASHTO T 228	1.03
5.	Softening Point	AASHTO T 53	50 °C
6.	Penetration of Residue at 25 °C	AASHTO T 49	63.8

**1.23.7 Design Methods**

Two methods are used for the design of Flexible pavements which include

- Marshall Mix Design
- Super pave Mix Design

Here is an explanation of the two methods used for the design of flexible pavements.

**1.23.7.1 Marshall Mix Design**

The best asphalt mix design in a given application can be found using the Marshall mix design approach. The method involves mixing different

proportions of aggregate, bitumen, and filler, and then testing the resulting mixes to determine their properties such as stability, flow, and void content. The mix with the optimum properties is then selected for use in the pavement. The Marshall mix design method is relatively simple and inexpensive, and it has been used for many years to design flexible pavements. However, the method has some limitations. For instance, the technique does not take into account how the performance of an asphalt mix is affected by environmental factors or traffic loads.

#### 1.23.7.2 Superpave Mix Design

A more sophisticated approach compared to the Marshall mix design is the Superpave mix design. To forecast how asphalt mixes will behave under various traffic loading & environmental factors, Superpave mix design utilizes computer software. The software program takes into account the properties of the aggregate, bitumen, and filler, as well as the climate and traffic conditions in the area where the pavement will be constructed. However, it is also more complex and expensive. Superpave mix design is typically used for major road projects where long-term performance is critical.

Here we are interested in the Marshall mix design method.

#### 1.23.7.3 Marshal Mix Design

Bruce Marshall initially presented the Marshall Mix design in 1930. He was serving as a material engineer at the Mississippi state highway department. For the determination of optimum binder content (OBC), it is a very common and popular method. The only difference between the Marshall Mix design and the super pave is the use of a compactor. The gyratory compactor and the standard compactor. The Marshall Mix concept was eventually incorporated into the ASTM 1559 standard by the American Society of Testing Materials (ASTM). The specimen prepared by the Marshall Mix design is 1275gm. Usually, the no of blows given to the specimen depends upon the tendency of the traffic. For high traffic, the no of blows is 75 in the case of wearing surface, for medium traffic no of blows is 50 and for low traffic, no of blows is 35.

##### 1.23.7.3.1 Mix Design

All of the components of hot mix asphalt must be blended to the proper degree in order to get the ideal binder content. The quantity of binder and aggregate utilized in the mix has a significant impact on the hot mix's physical characteristics. The Marshall mix design criterion was applied to determine these qualities, as illustrated in Figure 3.4.

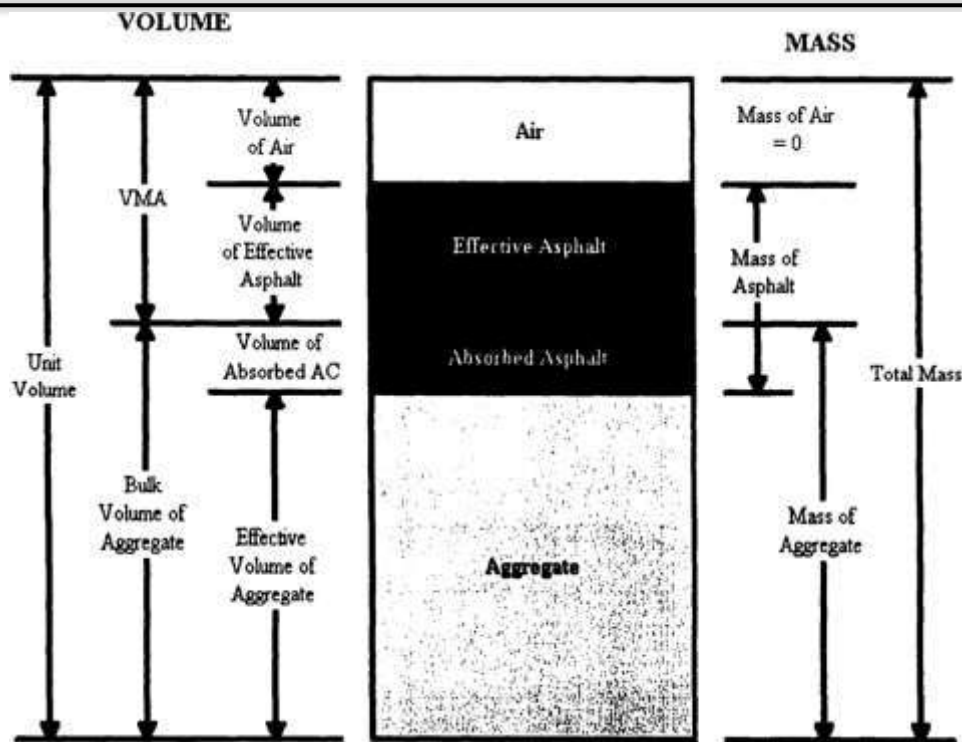


Figure 0-4: Component diagram of the compacted sample of the (HMA)[18]

1.23.7.3.2 Volumetric Analysis

For ease of use, proportions of mixed components are blended by mass and given as a percentage of the total mix. The ratios of the various aggregates and fillers, as well as the individual materials'

specific gravities, all have an impact on the mix's volume.

If porous aggregate exists, how much asphalt binder is absorbed and how much asphalt binder is not absorbed[19].

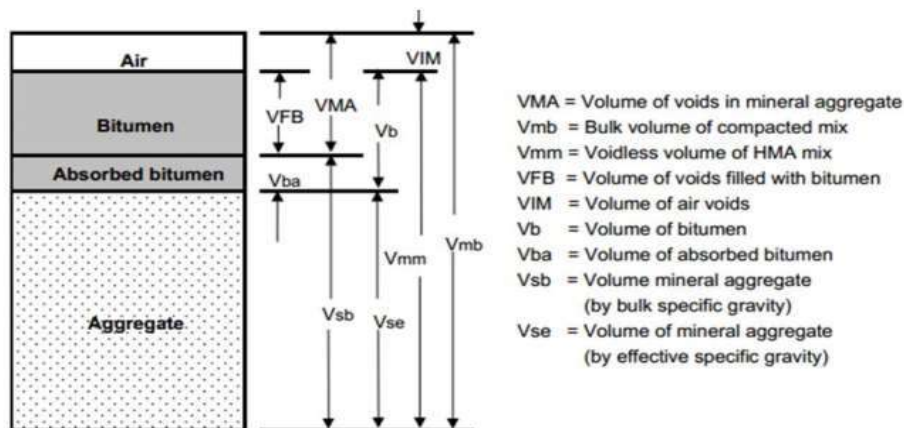


Figure 0-5: Volumes in Compacted HMA Specimen Represented (Asphalt Institute MS-2, 1994)

1.23.7.4 Characteristics and Behavior of Mix Design

The Marshall Mix design criterion is expected to improve on the five qualities. These include the mix's density, binder content (BC), voids filled in

the asphaltic substance (VFA), voids in the mineral aggregate (VMA), and air spaces in the mix. These all properties were to be enhanced by the volume or by specifying it by the weight of the

bitumen. Because the effect of these properties was found in the volumetric conditions.

#### 1.23.7.4.1 Bulk Specific Gravity

It is discovered that the amount weighed of the substance is equal to the volume of water or has the same specific gravity as water. It is an important factor and for a better life pavement, it should have to be calculated. The calculation unit for the bulk specific gravity is pound per cubic foot. Bulk specific gravity is a word that is frequently used to describe the weight of the asphaltic mixture's particular volume. It helps us in the conversation of the units. Because the volumetric and the terms in weight both are required for the mix.

#### 1.23.7.4.2 Air voids

The spaces that remain inside the finally compacted hot mix are to be termed the air voids. To prevent rutting, shoving, and flushing, the hot mix must have a certain number of voids. An increment or a decrement can be occurred by in the air voids by the variation in the bitumen content. Another method for the change in the air voids is the addition of fines that is passed from sieve No 200. If the air void content is high, then the air and water can easily enter the asphaltic mixture and it damages the mix. The density and the air voids have a relation with each other. The percentage of air voids in hot mix asphalt will be

lower if the density is high. The percentage of air spaces will be higher if the density is lower. In order to reach the ideal level of binder content, the right proportions of air voids must be taken into account in the hot mix asphalt.

#### 1.23.7.4.3 Voids in the Minerals of the Aggregate (VMA)

The voids in the aggregate's mineral are discovered to be the spaces left within the aggregates & the minerals. The spaces that will be filled by the binder are additionally included in the mineral aggregate voids. The representation of the space that is for the accommodation of the volume binder is known to be the voids in the mineral aggregate. The volume of the air voids is quite necessary for the hot mix asphalt. If there is a thick coating of the film occurred on the aggregates used, then the asphaltic mixture will be having more durability.

Other factors that can affect the VMA are fine particles that are passed from sieve no 200. The affection is just because of the absorption of these particles by the binder film. The gradation curve, the shape of the aggregates and the compaction are also involved in these factors. If the values of the VMA will be minimum, then the asphalt binder will be having more durability. If there is an increase in the binder content, then this will cause the rutting phenomenon.

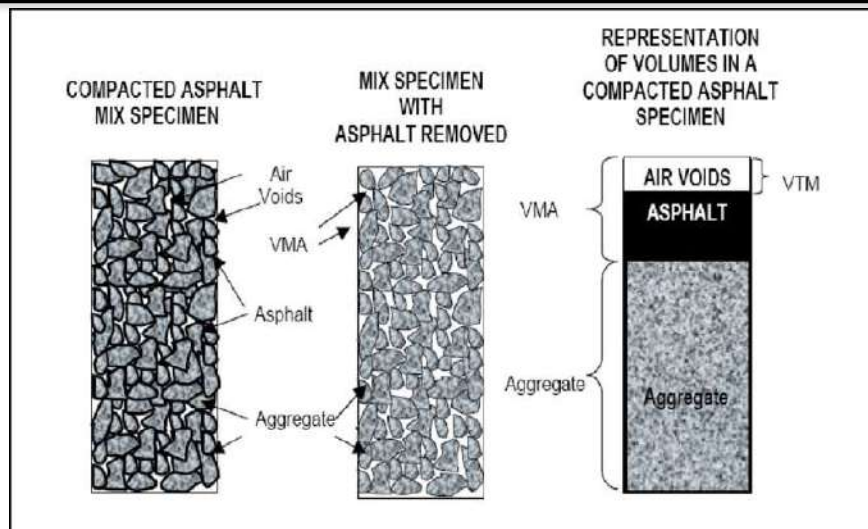


Figure 0-6:VMA behaviour of the compacted sample[20]

#### 1.23.7.4.4 Voids Filled with Asphalt (VFA)

The percentage determination by the voids mineral aggregate (VMA) that consists of a binder or bitumen is known as voids filled with asphalt. The compacted asphalt mixture and the aggregates that contain voids are to term as the (VFA). The values of the (VMA) are to be acceptable by (VFA). The limitation of the (VMA) and the binder content can be done by (VFA). If the air void content mixture wanted to be reduced, then it can be done by (VFA). The main benefit of the (VFA) is to make the strong durability of the hot mix asphalt. The low air voids content has a critical situation among the hot mix asphalt. The passing of the VFA requirement by heavy traffic is not possible, if the air void content is low. VFA values have many advantages like to resist the mixture that is having the rutting caused due to the overloading conditions. Besides this, it is also very helpful in the permanent deformation of the flexible pavement.

#### 1.23.7.5 Binder Content

The amount of bitumen that is used to prepare the hot mix asphalt is commonly termed the binder content. It can determine by using the mix design. It depends upon the properties of the aggregates used in the mix and the other characteristics such as the absorption and the gradation of the bitumen. The gradation curve of the aggregates has

a direct interaction with the binder content. If the gradation of the asphalt mix is done finer the amount of the aggregates will be larger amount of the binder content will be required to mix up with the aggregate particles. If the coarse aggregates are more in the gradation, then the binder content will be used in fewer amounts. This is one of the reasons that in surface asphalt mixture the amount of bitumen is high as compared to the base asphalt mixture. The amount of bitumen should not be decreased in the mixture as it is possible to have dryness in the hot mix and the mix can become brittle. By decreasing the amount of the binder content, the flushing can be reduced. The effective binder content can be evaluated by using bulk specific gravity and effective specific gravity. There are two phenomena used in the binder content one is the effective binder content which is the theoretical value of the binder content and the extracted binder content is the value obtained from the test.

## RESULTS AND DISCUSSION

### 1.24 Introduction

In this chapter, we present the experimental methodology and procedures employed to evaluate the performance of Hot Mix Asphalt (HMA) incorporating nano silica and fly ash additives using the Marshall stability test. The objective of this chapter is to outline the specific test conducted, the equipment and materials used,

and the procedures followed to assess the impact of these additives on the Marshall stability of HMA.

The Marshall stability test is a widely used method for measuring the strength and deformation characteristics of asphalt mixtures. It provides valuable information on the ability of the mixture to withstand applied loads and resist permanent deformation. By conducting the Marshall stability test on HMA samples with nano silica and fly ash additives, we aim to determine the effect of these additives on the strength and stability of the asphalt mixture.

This chapter serves as a foundation for the subsequent chapters and provides the necessary details of the experimental methodology and test procedures for the Marshall stability test. The results obtained from this test will contribute to a comprehensive understanding of the performance evaluation of HMA incorporating nano silica and fly ash, specifically in terms of stability. These insights can inform future pavement design and construction practices, leading to improved road infrastructure.

### 1.25 Specimen Preparation

The ratios of the filler material, coarse aggregate, and fine aggregate must adhere to the requirements of the relevant standards. In order to produce samples of compacted bituminous mix which are roughly 63.5 mm thick, the required amount of the mixture is utilized. A total of 1200 g of aggregate & filler are required to reach the desired thickness. A temperature of 175° to 190°C is applied to the aggregates. The compaction mold assembly, which consists of a rammer, is kept neat and heated with a temperature between 100°C & 145°C. After the bitumen has been heated to a temperature of 121°C and 138°C, the required amount of first trial bitumen will be added to the heated aggregate and thoroughly mixed. After being put into a mold, the mixture is squeezed with the necessary number of blows. After a brief interval, the sample is extracted from the mold using a sample extractor. The Marshall Mix Design technique is described here. It is subsequently illustrated in the figure below.



Figure 0-1: Selection of aggregate



Figure 0-2: Mixing of aggregate and binder content



Figure 0-4: Compacted samples



Figure 0-3: Rammer



Figure 0-3: Weight of sample in air and water

### 1.26 Test Procedure

1. Specimens had been heated to 60°C or less in a water bath for 30–40 minutes, or for a minimum of two hours in an oven.
2. The specimens are placed in the lower portion of the breaking head after being removed from the oven or water bath. The complete assembly, along with the upper portion of the specimen's breaking head, is placed on the testing apparatus.

3. The flow gauge is placed above one of the posts with the display set to zero.
4. Until a maximum load reading is reached, the load is being applied at a rate of 50 millimeters per minute.
5. The maximum load, measured in Newtons, is noted. At the same time, the flow as measured using the flow meter in mm units was recorded.



Figure 0-4: Giving heat to the sample in the water bat.



Figure 0-5: Marshall apparatus

**1.26.1 Testing and Analysis of control sample**  
 To estimate the Optimum Bitumen Content (OBC), Marshall stability experiments were performed on asphalt mixtures utilizing control

samples containing different amounts of bitumen (3.5%, 4%, 4.5%, and 5%). To determine the binding content needed to achieve the best Marshall stability, three samples were developed.

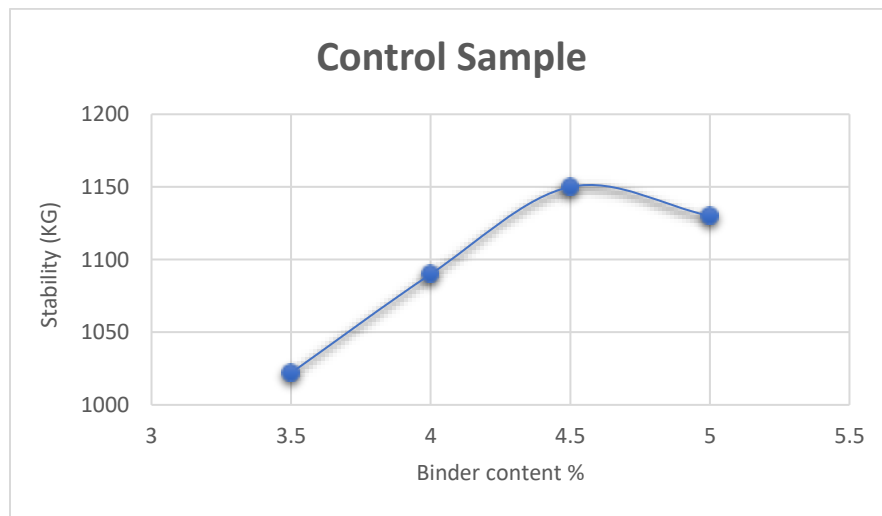
**Table 0-1: Test and analysis of the control sample**

Control Sample							
Binder Content % (BC)	Stability (KG)	Flow (mm)	Air Void (%)	VFA (%)	VMA (%)	Gmb (g/cm <sup>3</sup> )	
3.5	1022	8	6.8	46	14.39	2.21	
4	1090	8.1	5.9	56	14.1	2.31	
4.5	1150	8.3	4.0	69	14.2	2.36	
5	1130	9	4.2	73	14.39	2.32	

**Marshall Stability**

Up to a specific binder level, stability value is seen to rise with higher binder content before

declining. Figure 4.8 displays the variation in Marshall Stability value based on different binder contents.



**Figure 0-6: Stability vs Binder content**

**1.26.2 Unit Weight**

Up until a specific binder level, it has been observed that the unit's weight increases with an increase in binder content before declining. Figure 4.9 illustrates the variation in unit weight value with varied binder and filler contents.

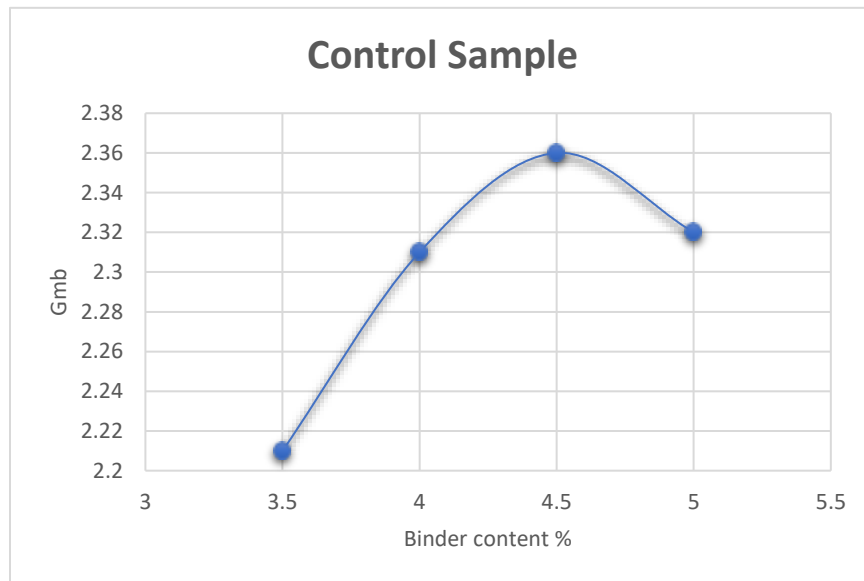


Figure 0-7: Unit weight vs Binder content

### 1.26.3 Voids in Mineral Aggregate (VMA)

It is noted that it initially drops before increasing. Figure 4.10 displays a variation of VMA with varied binder content.

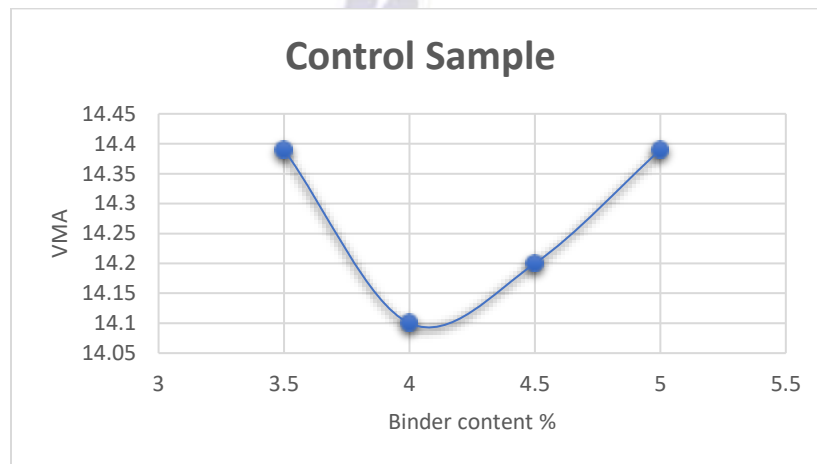


Figure 0-8: VMA vs Binder content

### 1.26.4 Flow Value

It has been seen that binder content flow value increases with increasing. Figure 4.11 depicts the variation of flow value with various binder contents.

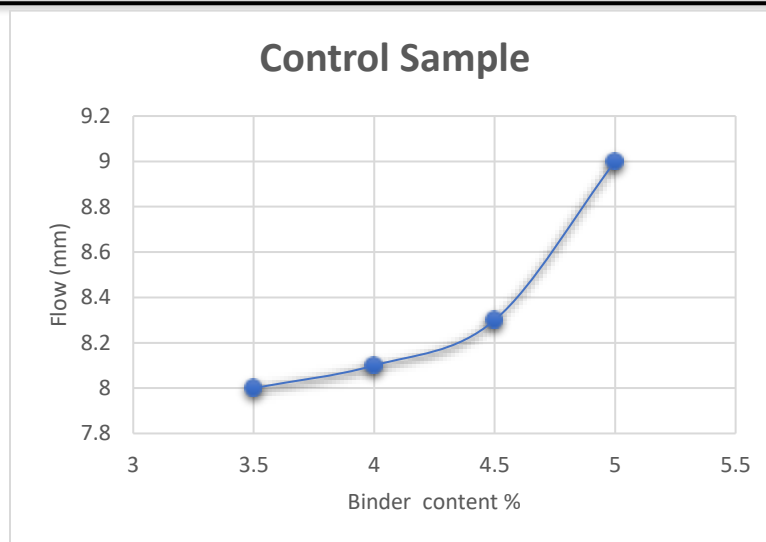


Figure 0-9: Flow vs Binder content

### 1.26.5 Air Void

Air void is seen to diminish with higher binder content. Figure 4.12 illustrates the variation in air void with several binders.

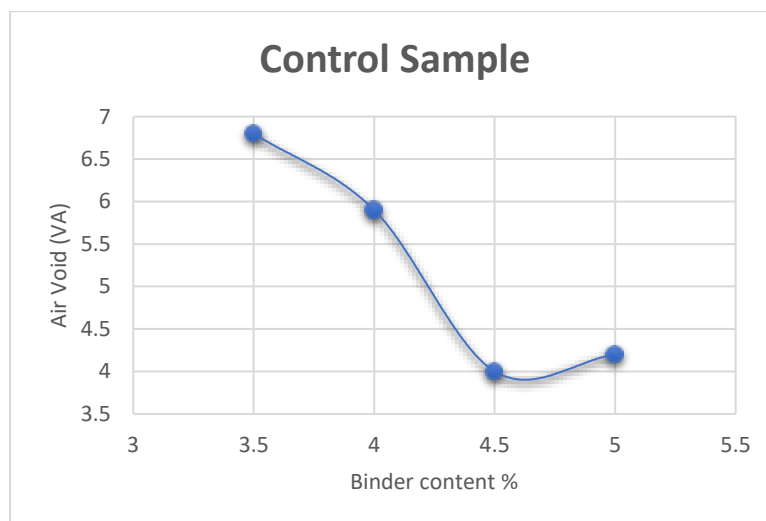


Figure 0-10: Air Void vs Binder content

### 1.26.6 Void filled with aggregate (VFA)

With more binder content, VFA rises. Figure 4.13 depicts a variation of VFA with variable binder contents.

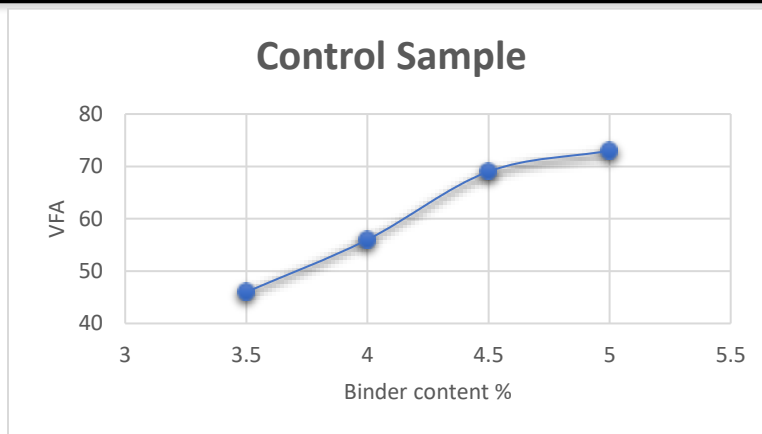


Figure 0-11: VFA vs Binder content

### 1.27 Optimum Binder Content

According to the recommendations of the National Asphalt Pavement Association (NAPA), the ideal asphalt content is only the amount of asphalt that results in 4% air spaces. This is because 4% air voids are the optimum level of air voids for asphalt mixes. Asphalt mixed with too few air voids will be too stiff and will not be able to drain water away properly. Asphalt mixed with too many air voids will be too soft and will not be able to support traffic loads.

For the majority of applications, asphalt mixes containing 4% air voids have been determined to provide the greatest combination of

characteristics. For this reason, the NAPA states that the ideal asphalt content is just the amount of asphalt that results in exactly 4% air spaces.

Of course, the optimum asphalt content may vary depending on the specific application. For example, asphalt mixes for use in hot climates may need to have a higher air void content to allow for more drainage. However, for most applications, 4% air voids are a good target.

From our tests and experiments, we found 4% air voids at the binder content of 4.5% which is our optimum binder content.

For research work, we should take binder content of 4.5% and the percentage of filler is as follows.

Table 0-2: Total Filler samples

Fly Ash	4%	8%	12%
Nano silica	2%	4%	6%
Binder content	4.5%	4.5%	4.5%
Total samples	3	3	3

### 1.28 Tests and analysis of Fly Ash (FA), Nano silica (NA) and OBC 4.5%

Table 0-3: Results of Filler samples

S.no	Filler samples	Stability (KG)	Flow (mm)	Air Void (VA)	VFA (%)	VMA (%)	Gmb (g/cm <sup>3</sup> )
1	4.5% BC, 4% FA and 2% NS	1225	8	4.3	70.5	14.5	2.39
2	4.5% BC, 8% FA and 4% NS	1310	7.2	4	72	14.7	2.41
3	4.5% BC, 12% FA and 6% NS	1255	7.5	4.1	70	14.1	2.44

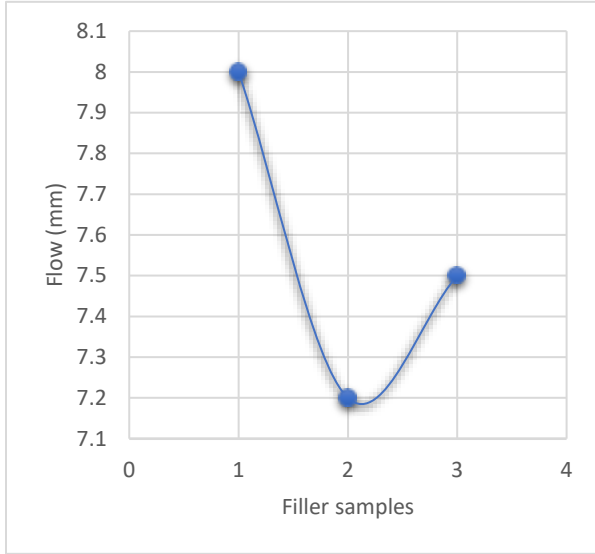


Figure 0-14: Stability vs Filler samples

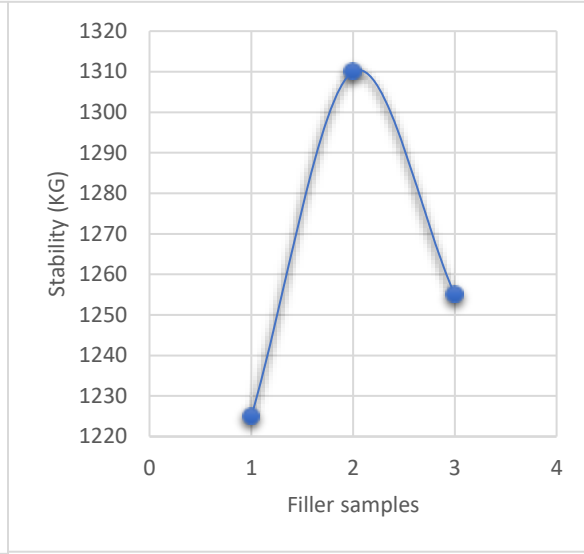


Figure 0-15: Flow vs Filler samples

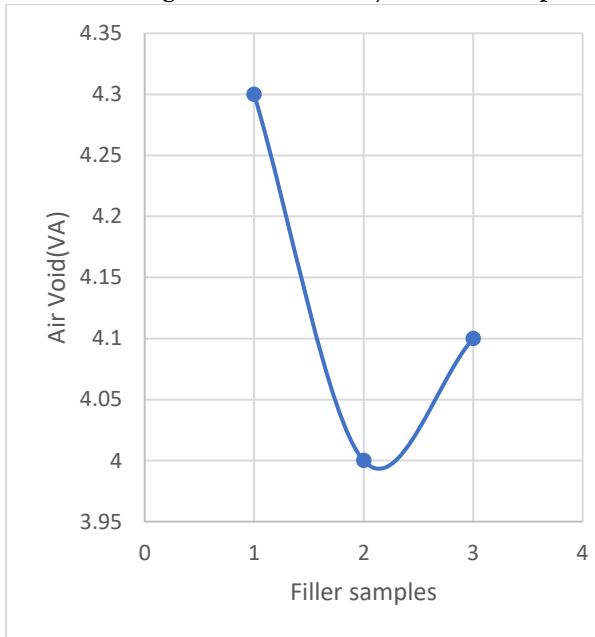


Figure 0-16: Air Void vs Filler samples

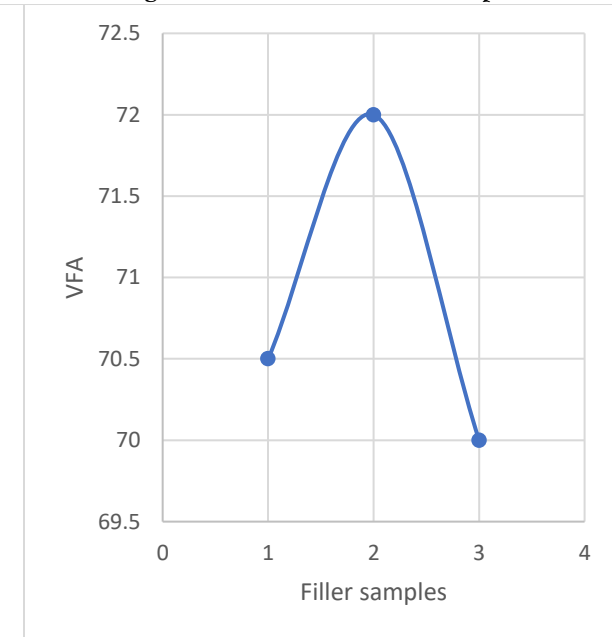


Figure 0-17: VFA vs Filler samples

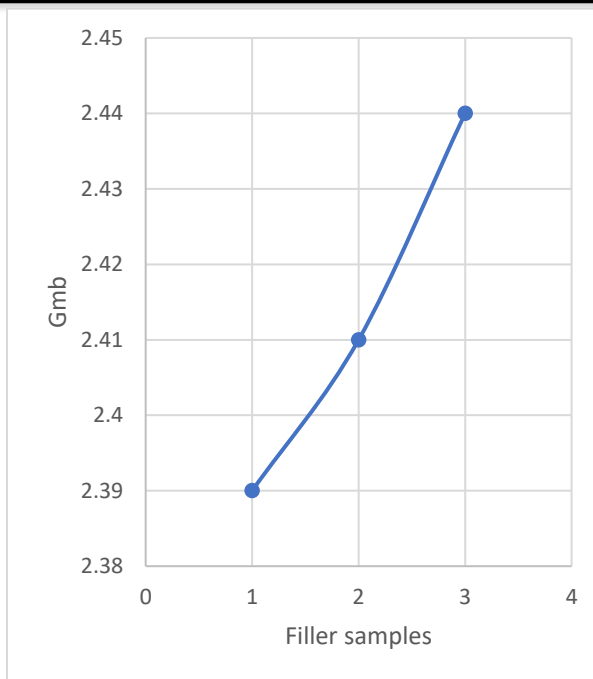


Figure 0-13:VMA vs Filler samples

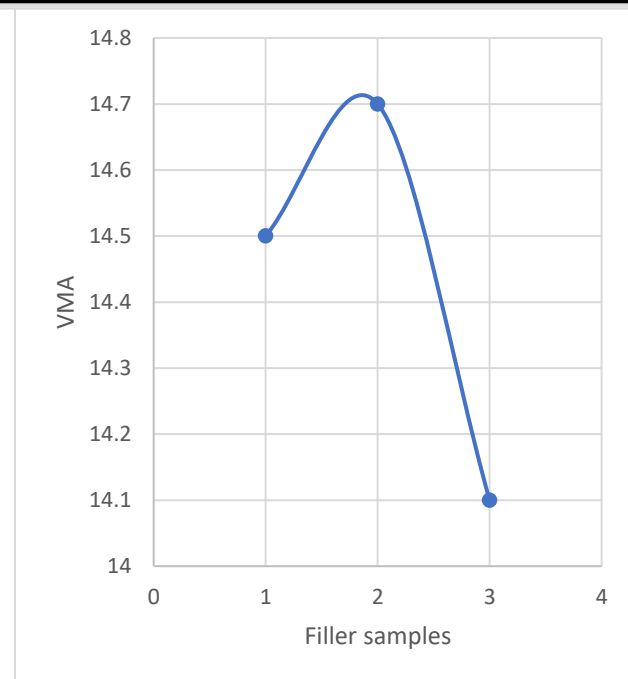


Figure 0-12: Gmb vs Filler samples

## CONCLUSIONS AND RECOMMENDATIONS

### 1.29 Conclusions

1. The usage of significant quantities of non-renewable natural resources by the building sector raises serious concerns about environmental contamination and environmental degradation. Recycling industrial trash is one of the options being discussed globally for resource efficiency and environmental protection. This study's main goal is to examine how well nano silica and fly ash waste function as fillers in hot asphalt mixtures. The following findings are drawn from laboratory test and analytical data.

2. The following conclusions are made based on obtained results.

3. From our experiments and research work we indicate that the mixing of 4% Nano silica and 8% Fly Ash with a binder content of 4.5% yield a mix with greater stability compared to other percentage variations in the Marshall mix. It is noteworthy that all other mixes with different percentages exhibit lower stability values.

4. Furthermore, the mix with 4% Nano silica and 8% Fly Ash, along with a binder content of 4.5%, demonstrates a void percentage of 4.2,

which falls within the desired range of 4-7%. This indicates that the mix has a suitable void content for durability.

5. Moreover, the same mix exhibits a flow value of 7.2mm, which is lower than all the other mixes tested. This lower flow value suggests enhanced resistance to deformation, which is a desirable characteristic in asphalt mixtures

6. These findings provide important insights into the influence of the percentages of Nano silica, Fly Ash, and binder content on the stability, void content, and flow of the Marshall mix. The results highlight the potential of the mix with 4% Nano silica and 8% Fly Ash, along with a binder content of 4.5%, as a promising combination for achieving improved stability and performance in asphalt mixtures.

### 1.30 Recommendations

1. The stability of the mix with 4% Nano silica and 8% Fly Ash, along with a binder content of 4.5%, surpasses not only all the other mixes tested but also the conventional asphalt. This indicates that this particular combination exhibits greater engineering properties, suggesting improved resistance to deformation and higher

overall stability. Based on these findings, it is recommended to utilize this combination in future works for its enhanced performance.

2. The mix with 4% Nano silica and 8% Fly Ash shows a flow value of 7.2mm, which slightly exceeds the specified limit. However, this minor deviation can be effectively addressed by incorporating polymer-modified bitumen into the mix. Polymer modification has the potential to control and reduce the flow value, ensuring that it falls within the desired range. Thus, implementing polymer-modified bitumen can mitigate the issue and bring the mix within the specified limits.

3. It is important to note that the flow value of the mix with 4% Nano silica and 8% Fly Ash is lower than the flow values observed in all the other mixes with different percentages. This lower flow value indicates improved resistance to deformation and better workability, which are desirable characteristics in asphalt mixtures. Therefore, the mix with 4% Nano silica and 8% Fly Ash exhibits superior flow properties compared to the other tested combinations.

4. These findings and recommendations highlight the potential and advantages of utilizing the mix with 4% Nano silica and 8% Fly Ash, along with a binder content of 4.5%, in future projects. The mix shows enhanced stability, with the flow value being the only aspect that requires attention, which can be effectively controlled through the implementation of polymer-modified bitumen.

#### Acknowledgement

We express our profound gratitude and appreciation to Allah, the ultimate source of knowledge and wisdom, whose blessings have enabled us to successfully complete this project. This achievement wouldn't have been achievable without Allah's support and guidance.

We are extremely grateful to our supervisor Dr Muhammad Waseem, whose sincere guidance and intellectual approach have played a pivotal role in the successful culmination of this research work. His constant advice and supervision have been instrumental in driving us towards excellence and we are truly indebted to him for his support.

We would also like to extend our thanks to Dr Muhammad Tariq, our co-supervisor for his valuable and timely assistance throughout this research endeavor.

Last but not least, we want to thank everyone who helped out and supported us throughout this study project.

#### Dedication

We dedicate this work to our parents, whose love, support, and encouragement have been invaluable throughout our program. Their unwavering belief in us and the dreams they have held for us serve as the driving force behind our achievement. We also express our gratitude to our siblings, relatives, classmates, and friends for their advice, encouragement, and shared experiences, which have played a significant role in our journey. Their unwavering support and belief in our abilities have been instrumental in our success.

5.

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